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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-13, 14, AND 15)

H. J. Counts, Jr.

ARO, Inc.

February 1968

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LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-13, 14, AND 15)

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (I-E-J), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under contract AF40(600)-1200. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Aviation, Inc., Rocketdyne Division, manufacturer of the J-2 rocket engine, and Douglas Aircraft Company, manufacturer of the S-IVB stage. The testing reported herein was conducted on October 24, 31, and November 7, 1967, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on December 13, 1967.

This technical report has been reviewed and is approved.

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ABSTRACT

Six firings of the Rocketdyne J-2 rocket engine were conducted during test periods J4-1801-13, 14, and 15 on October 24, 31, and November 7, 1967, respectively, in Test Cell J-4 of the Large Rocket Facility. These firings were accomplished at pressure altitudes ranging from 98,000 to 107,000 ft to evaluate fuel pump start transient performance utilizing lower than minimum engine model specification fuel pump inlet pressure as required on AS-503 and subsequent flights. Engine components were thermally conditioned to temperatures observed in the S-II interstage/engine environment during the flight AS-501 countdown demonstration. The accumulated firing duration was 100.84 sec.

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NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start, designated as the time that the helium control and ignition phase solenoids are energized
GG	Gas generator
MOV	Main oxidizer valve
NPSH	Net positive suction head, ft
PCGG	Gas generator chamber pressure
PFPD	Fuel pump discharge pressure
STDV	Start tank discharge valve
t_0	Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, defined as engine vibration in excess of 150 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The six firings reported herein were conducted during test periods J4-1801-13, 14, and 15 on October 24, 31, and November 7, 1967, respectively, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF). These firings were to investigate J-2 engine S-II/S-V start transients utilizing a lower than minimum engine model specification fuel pump inlet pressure as required on AS-503 and subsequent flights. The firings were accomplished at pressure altitudes ranging from 98, 000 to 107, 000 ft (geometric pressure altitude, Z, Ref. 1) at engine start. Engine components were thermally conditioned to temperatures observed in the S-II interstage/engine environment during flight AS-501 countdown demonstration.

Data collected to accomplish the test objectives are presented herein. The results of the previous test periods are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Aviation, Inc. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 225, 000 lb_f at an oxidizer-to-fuel mixture ratio of 5. 5. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively. The thrust chamber heater blankets were in place during this test period, although they were not utilized.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 35,517 ft (1225 psia) of liquid hydrogen at a flow rate of 8414 gpm for a rotor speed of 26,702 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2117 ft (1081 psia) of liquid oxygen at a flow rate of 2907 gpm for a rotor speed of 8572 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel

turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46, 000 lb of liquid hydrogen and 199, 000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during S-II flight were routed to the respective facility venting systems.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100, 000 ft. The basic cell construction provides a 1. 5-million-lbf-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, main oxidizer valve second-stage actuator, and start tank discharge valve. Helium was routed internally through the crossover duct and tubular-walled thrust chamber. The main oxidizer valve second-stage actuator was conditioned by opening the prevalves and permitting oxidizer into the engine. An external ambient helium purge was utilized to keep the actuator temperature within the desired target region.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Engine side loads were measured with dual-bridge, strain-gage-type load cells which were laboratory calibrated before installation. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers, load cells, and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape, (2) single-input, continuous-recording FM systems recording on magnetic tape, (3) photographically recording galvanometer oscillographs, (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts, and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III
PROCEDURE

Pre-operational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber, the crossover duct, main oxidizer valve second-stage actuator, and start tank discharge valve. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Six firings of the J-2 rocket engine (S/N J-2047) were conducted during test periods J4-1801-13, 14, and 15 on October 24, 31, and November 7, 1967, respectively, for a total firing duration of 100.84 sec. The accumulated total firing duration of this engine at AEDC through Test 15 is 161.44 sec.

The main objective of these firings was to investigate J-2 engine S-II/S-V start transient utilizing a lower than minimum engine model specification fuel pump inlet pressure as required on AS-503 and subsequent flights. Testing was accomplished at pressure altitudes ranging from 98,000 to 107,000 ft at engine start and with predicted S-II interstage/engine temperature conditions as the targets for conditioning engine components. Test requirements and specific test results are summarized in Table VI. Start and shutdown transient operating times for selected engine valves are presented in Table VII. Figure 8 shows engine start conditions for pump inlets, start tank, and helium tank.

Although each test period was scheduled to include four engine firings and one start tank discharge test, none of the three test periods were completed as planned. Test period J4-1801-13 was cancelled after two successful firings because of temperature conditioning difficulties in the oxidizer pump inlet. Test period J4-1801-14 was cancelled after one successful firing because the main oxidizer valve was slow in closing. Test period J4-1801-15 was cancelled after two successful firings and a start tank discharge test because of an augmented spark igniter ignition detect probe failure. Specific test objectives and a brief summary of results obtained for each firing are presented as follows:

	Test Objectives	Test Results
13A	Conduct a 30-sec firing to obtain a maximum S-II thrust chamber buildup time and a possible high level fuel pump stall.	Chamber pressure buildup time for this firing was 2.245 sec. Gas generator outlet temperature peaked at 1460°F. A second gas generator outlet temperature peak did not occur. No fuel pump stall tendency was noted.

	Test Objectives	Test Results
13B	Conduct a 5-sec duration firing which could produce a low level fuel pump stall, a high gas generator outlet temperature second peak, and augmented spark igniter erosion.	No fuel pump stall tendency was noted. Gas generator outlet temperature peaked at 1390°F and experienced a second peak of 1510°F. No augmented spark igniter erosion was noted.
14A	Conduct a 30-sec firing to obtain a maximum S-II thrust chamber buildup time and a possible high level fuel pump stall.	Chamber pressure buildup time for this firing was 2.174 sec. Gas generator outlet temperature peaked at 1180°F and experienced no second peak. The margin between stall inception data and start transient fuel pump head/flow data was conservative.
15A	Conduct a 30-sec firing to obtain a maximum S-II thrust chamber buildup time and a possible high level fuel pump stall.	Chamber pressure buildup time for this firing was 2.090 sec. Gas generator outlet temperature peaked at 1240°F and experienced no second peak. No fuel pump stall tendency was noted in the region above 17,500 rpm.
15B	Conduct a 5-sec firing to evaluate S-II start conditions which could produce fuel pump cavitation, a high gas generator outlet temperature first peak, and augmented spark igniter erosion.	The extent of cavitation, if any, was not determined. Gas generator outlet temperature initial peak was 1710°F with no second peak observed. No augmented spark igniter erosion was noted.
15E	Conduct a start tank discharge test to evaluate the effect of fuel acceleration pressure loss in the fuel low pressure duct on fuel pump performance.	Fuel pump and oxidizer pump peak spin speeds were 13,900 and 3690 rpm, respectively. Calculated minimum NPSH was 82 ft. No fuel pump stall tendency was noted.

The presentation of the test results in the following sections will consist of a discussion of each engine firing with pertinent comparisons.

The data presented will be those recorded on the digital data acquisition system, except as noted.

4.2.1 Firing J4-1801-13A

The programmed 30-sec engine firing was successfully accomplished. Test conditions at engine start are presented in Table VI. Engine start and shutdown transients are shown in Figs. 9 and 10, respectively. Table VII presents selected engine valve operating times for start and shutdown. Engine ambient pressure altitude at engine start was 98, 000 ft and averaged 94, 000 ft during main-stage operation. Figure 11 presents engine ambient pressure and combustion chamber pressure for the duration of the firing. The propellant utilization valve excursion, which changed engine mixture ratio from 5.0 to 5.5, is reflected in a combustion chamber pressure increase at about t_0 + 14 sec. Thermal conditioning history of engine components is shown in Fig. 12.

Test conditions for firing 13A were selected to obtain a maximum S-II thrust chamber pressure buildup time and a possible high level fuel pump stall. Main-stage operation (chamber pressure of 550 psia) was attained at t_0 + 2.245 sec. Thrust chamber ignition (chamber pressure attains 100 psia) occurred at t_0 + 1.043 sec with 33 msec of engine vibration (VSC). Second-stage movement of the main oxidizer valve began at t_0 + 0.982 sec. Movement at this time may be attributed to a low net opening torque (73 in.-lb) and a low hydraulic torque which is peculiar to S-II low energy starts.

Gas generator outlet temperature peaked at 1460°F. There was no second peak because the main oxidizer valve moved from the 14-deg plateau before conditions conducive to a second peak could be established (Ref. 5). A negative differential pressure [ΔP = (PFPD) - (PCGG)] at gas generator ignition has been noted on all S-II starts to date at AEDC having cold thrust chambers (-250°F). However, because of the short delay and travel times of the start tank discharge valve, the gas generator chamber pressure (initially an indication of start tank discharge pressure) was essentially equal to fuel pump discharge pressure at gas generator ignition. Therefore, the differential pressure across the gas generator fuel injector was virtually zero.

Fuel pump start transient performance is shown in Fig. 13. Transient fuel pump head/flow data showed the stall margin was conservative.

The only other S-II slow thrust chamber pressure buildup firing of the J-2 rocket engine at AEDC was firing J4-1554-29A (Ref. 5).

The time to main-stage operation for this firing was 2.054 sec. Gas generator outlet temperature first peak was 1590°F with no second peak. Movement of the second stage of the main oxidizer valve began at t_0 + 0.974 sec which was 52 msec before thrust chamber ignition.

Engine steady-state performance data are displayed in Table VIII. The data presented were for a 1-sec time slice from 29 to 30 sec and were computed using the Rocketdyne PAST 640, modification zero, performance computer program. Engine test measurements required by the program and program computations are presented in Appendix IV.

4.2.2 Firing J4-1801-13B

The programmed 5-sec engine firing was successfully accomplished. Test conditions at engine start are tabulated in Table VI. Table VII presents start and shutdown transient operating times for selected engine valves. Engine ambient pressure altitude at engine start was 106,000 ft. Engine ambient pressure and combustion chamber pressure for the duration of the firing are shown in Fig. 14. Thermal conditioning history of engine components is shown in Fig. 15.

Engine start and shutdown transients are shown in Figs. 16 and 17, respectively. Thrust chamber ignition occurred at t_0 + 0.980 sec with 7 msec of engine vibration (VSC). Gas generator outlet temperature peaked at 1390°F and experienced a second peak of 1510°F. This second peak was influenced by the main oxidizer valve remaining on the 14-deg plateau until t_0 + 1.187 sec. Calculated main oxidizer valve net opening torque was 365 in.-lb. This value is greater than the nominal 275 in.-lb, but is consistent with other firings having a cold (-150 to -250°F) main oxidizer valve second-stage actuator.

Fuel pump start transient performance is shown in Fig. 18. A conservative stall margin was maintained throughout the start transient.

Posttest inspection showed the engine to be in satisfactory condition. No augmented spark igniter erosion was noted. Because of the oxidizer pump inlet temperature conditioning difficulty, an oxidizer sample was taken during posttest detanking procedures. This sample revealed a nitrogen content of 2.92 percent by volume.

4.2.3 Firing J4-1801-14A

The programmed 30-sec engine firing was successfully accomplished. Test conditions at engine start are shown in Table VI.

Start and shutdown transient operating times of selected engine valves are tabulated in Table VII. Valve operating times were normal except for the main oxidizer valve shutdown transient which was longer than normal. Engine start and shutdown transients are shown in Figs. 19 and 20, respectively. Engine ambient pressure altitude at engine start was 106,000 ft and averaged 100,000 ft during main-stage operation. Figure 21 presents engine ambient pressure and combustion chamber pressure for the duration of the firing. There was no propellant utilization valve excursion because pressurization of the vehicle oxidizer tank after engine start was not sufficient to maintain an adequate NPSH for engine operation at a 5.5 mixture ratio. Thermal conditioning history for engine components is shown in Fig. 22. Engine steady-state performance data are presented in Table VIII.

Test requirements and objectives for firing 14A were identical to those for firing 13A. Main-stage operation was attained at t_0 + 2.174 sec with thrust chamber ignition occurring at t_0 + 1.059 sec. There were 129 msec of engine vibration (VSC) during thrust chamber ignition. Consistant with low energy S-II starts, the main oxidizer valve lifted from the 14-deg plateau 39 msec before thrust chamber ignition. Calculated main oxidizer valve net opening torque at initial second-stage movement was 137 in.-lb. The gas generator outlet temperature peaked at 1180°F and experienced no second peak.

Fuel pump start transient performance is presented in Fig. 23. A conservative stall margin was maintained in the region of concern above 17,500 rpm.

Since a posttest 13 oxidizer sample showed a high nitrogen content, oxidizer samples were taken before and after firing 14A. Prefire samples were taken at 11:20 hr (after loading the vehicle tank) and at 13:20 hr (after propellant conditioning for 2 hr). Chemical analysis of these samples showed 3.47- and 2.25-percent nitrogen by volume, respectively. Although these samples indicated the nitrogen content to be considerably higher than the specification of the engine manufacturer (0.80-percent total impurities), the planned test period was conducted to obtain engine performance data at a known nitrogen contamination level.

Two postfire samples were also taken. These samples revealed 3.14-percent nitrogen by volume at 17:40 hr (approximately one hour after refilling the vehicle tank) and 2.99-percent nitrogen by volume at 19:10 hr (during posttest detanking procedures).

Posttest inspection revealed no augmented spark igniter erosion. The inspection also showed a loose retainer on the restrictor check valve on the main oxidizer valve. This caused the slow main oxidizer valve closing.

4.2.4 Firing J4-1801-15A

The planned 30-sec firing was successfully accomplished. Tables VI and VII present test requirements and conditions at engine start, and start and shutdown transient operating times for selected engine valves, respectively. Engine start and shutdown transients are shown in Figs. 24 and 25, respectively. Engine ambient pressure altitude at engine start was 100,000 ft and averaged 95,000 ft during main-stage operation. Figure 26 shows engine ambient pressure and combustion chamber for the duration of the firing. The increase in combustion chamber pressure at t_0 + 16 sec reflects the propellant utilization valve excursion, which changed engine mixture ratio from 5.0 to 5.5. Thermal conditioning history of engine components is shown in Fig. 27.

Test requirements and test objectives for firing 15A were identical to those for firings 13A and 14A. Main-stage operation was attained at t_0 + 2.090 sec. Thrust chamber ignition occurred at t_0 + 1.034 sec with 110 msec of engine vibration (VSC). Movement of the main oxidizer valve second stage began at t_0 + 1.004 sec. This is consistant with all S-II low energy starts. Main oxidizer valve net opening torque, calculated at initial second-stage movement, was 127 in.-lb (nominally 275 in.-lb). The gas generator outlet temperature peaked at 1240°F and experienced no second peak.

Fuel pump start transient performance is presented in Fig. 28. Transient fuel pump head/flow data showed a conservative stall margin in the region above 17,500 rpm.

Oxidizer samples were again taken on this test. One sample taken from the facility storage dewar before loading the vehicle tank showed 0.13-percent nitrogen by volume. The other sample, taken from the vehicle tank fill line during the loading procedure, showed less than 0.01-percent nitrogen by volume. Because of the high nitrogen content in the liquid oxygen during test 14, the storage dewar was completely emptied and refilled with military specification liquid oxygen after test 14. Helium was also used to pressurize the storage dewar for transfer pusposes.

During the first 16 sec of the firing, augmented spark igniter ignition detection was erratic. At t_0 + 16 sec, the reference element circuit opened and remained open for the duration of the firing. However, when the reference element circuit cooled, it regained continuity, and the decision was made to proceed to test 15B.

Engine steady-state performance data are presented in Table VIII. These data show engine performance to be higher for firing 15A than that of 13A. Since nitrogen content on tests before test 13 is unknown, it can not be determined if nitrogen is directly responsible for the lowered performance on firing 13A.

4.2.5 Firing J4-1801-15B

The programmed 5-sec duration firing was successfully accomplished. Test conditions at engine start are tabulated in Table VI. Table VII presents start and shutdown transient operating times for selected engine valves. Engine start and shutdown transients are shown in Figs. 29 and 30, respectively. Engine ambient pressure altitude at engine start was 103, 000 ft. Engine ambient pressure and combustion chamber pressure are shown in Fig. 31 for the duration of the firing. Thermal conditioning history of engine components is shown in Fig. 32.

Test conditions were selected to evaluate possible fuel pump cavitation, gas generator outlet temperature initial peak, and augmented spark igniter erosion. Main-stage operation was attained at t_0 + 1.954 sec. Thrust chamber ignition occurred at t_0 + 0.976 sec with 29 msec of engine vibration (VSC). Gas generator outlet temperature peaked at 1710°F and experienced no second peak.

Fuel pump start transient data are shown in Fig. 33. Fuel pump transient head/flow data showed the stall margin maintained was conservative. Because of a lack of critical NPSH data from the engine manufacturer showing the required NPSH to suppress cavitation during the period of fuel pump acceleration, no conclusion concerning fuel pump cavitation has been reached.

Detection of ignition in the augmented spark igniter chamber during the firing 15B start transient was erratic. Ignition was not detected until 292 msec after engine start. After this, the reference element circuit opened and did not regain continuity again. It was then decided to cancel 15C and 15D and proceed to firing 15E.

4.2.6 Firing J4-1801-15E

Firing 15E was a successful pump performance test, consisting of a start tank discharge with engine cutoff occurring at the expiration of the ignition phase timer (t_0 + 0.446 sec). Test conditions at engine start are presented in Table VI. Table VII presents start and shutdown transient operating times for selected engine valves. Engine ambient pressure altitude at engine start was 107,000 ft. Engine ambient pressure and combustion chamber pressure are shown in Fig. 34 for the duration of the firing. Thermal conditioning history of engine components is shown in Fig. 35. Engine start and shutdown transients are shown in Fig. 36. Fuel and oxidizer pump peak spin speeds were 13,900 and 3690 rpm, respectively, at t_0 + 0.680 sec. Fuel pump inlet static pressure reached a minimum of 21.6 psia at t_0 + 0.325 sec. Calculated NPSH for this pressure is compared in Fig. 37 with Rocketdyne-supplied critical NPSH steady-state data. Because of the unavailability of data from the engine manufacturer showing the required NPSH to suppress cavitation through the region of fuel pump acceleration, no conclusion has been reached concerning cavitation.

Fuel pump start transient performance data are shown in Fig. 38. A conservative margin was maintained between pump transient head/flow data and stall inception data.

Posttest inspection showed the engine to be in satisfactory condition. No augmented spark igniter erosion was noted.

4.2.7 Comparison of Tests J4-1801-13A, 14A, and 15A

Test requirements for firings J4-1801-13A, 14A, and 15A were identical. All were S-II/S-V slow thrust chamber pressure buildup, low energy starts. On all tests, the main oxidizer valve moved from the 14-deg plateau before thrust chamber ignition, which appears to be typical of S-II low energy starts. Because of a warm start tank discharge valve, there was virtually no negative differential pressure across the gas generator fuel injector at the time of gas generator ignition. Other important features are shown below.

Firing Number J4-1801-		13A	14A	15A
Main-Stage Operation Attained (PC = 550 psia), sec (Ref. t_0)		2.245	2.174	2.090
Thrust Chamber Ignition (PC = 100 psia), sec (Ref. t_0)		1.043	1.059	1.034
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)		0.982	1.020	1.004
Fuel Pump Spin Speed, at the Time of Oxidizer Pump Peak Spin Speed, rpm*		12,252	12,521	12,480
Oxidizer Pump Peak Spin Speed, rpm*		3038	3136	3091
Time of Peak Spin Speed, sec (Ref. t_0)		0.650	0.675	0.675
Gas Generator Outlet Temperature, °F	Initial Peak	1460	1180	1240
	Second Peak	---	---	---

*During start tank discharge

4.2.8 Temperature Effects on the Start Tank Discharge Valve

Thermal conditioning of the start tank discharge valve was requested for the first time at AEDC on test 13. This thermal conditioning was to more closely simulate S-II interstage/engine conditions as observed during flight AS-501 countdown demonstration. A minimum start tank discharge valve body temperature of 32°F was requested to be maintained for the duration of the test period.

Temperature effect on the start tank discharge valve is shown in Fig. 39. It may be seen that the warmer valve tends to have a shorter delay and travel time.

SECTION V
SUMMARY OF RESULTS

The results of the six firings of the Rocketdyne J-2 Rocket Engine conducted on October 24, 31, and November 7, 1967, in Test Cell J-4 are summarized as follows:

1. Firings J4-1801-13A, 14A, and 15A were repeated S-II/S-V slow thrust chamber buildup time firings. Times to main-stage operation (chamber pressure attained 550 psia) were 2.245, 2.174, and 2.090 sec, respectively.
2. Chemical analysis of the oxidizer used for tests 13 and 14 showed nitrogen content to be in excess of 2 percent by volume. Chemical analysis of the oxidizer used for test 15 showed nitrogen content to be less than 0.01 percent by volume.
3. Calculated engine performance for firing 13A was lower than that of firing 15A. However, since nitrogen content on tests prior to test 13 is unknown, no conclusion concerning the effect of nitrogen on engine performance can be drawn.
4. The main oxidizer valve moved from the 14-deg plateau before thrust chamber ignition during firings 13A, 14A, and 15A. This appears to be normal for an S-II low energy start.
5. All firings utilized a lower than minimum engine model specification fuel pump inlet pressure. No stall tendencies were noted.
6. Posttest inspection after each test period showed no augmented spark igniter erosion.
7. Start tank discharge valve delay and travel times tend to shorten as the valve body temperature increases.
8. Because of the short delay and travel times of the start tank discharge valve, the gas generator chamber pressure was essentially equal to fuel pump discharge pressure at gas generator ignition. Therefore the differential pressure across the gas generator fuel injector was virtually zero on firings 13A, 14A, and 15A.
9. Because of the unavailability of critical NPSH data, from the engine manufacturer during the period of fuel pump acceleration, no conclusion has been reached concerning cavitation.

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1. Dubin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.

2. Franklin, D. E. and Tinsley, C. R. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-11 and J4-1801-12)." AEDC-TR-67-278, January 1968.

3. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1, August 1965.

4. Test Facilities Handbook (6th Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, November 1966.

5. Vetter, N. R., Franklin, D. E., and Muse, W. W. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1554-27 through J4-1801-01)." AEDC-TR-67-180, November 1967.

APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

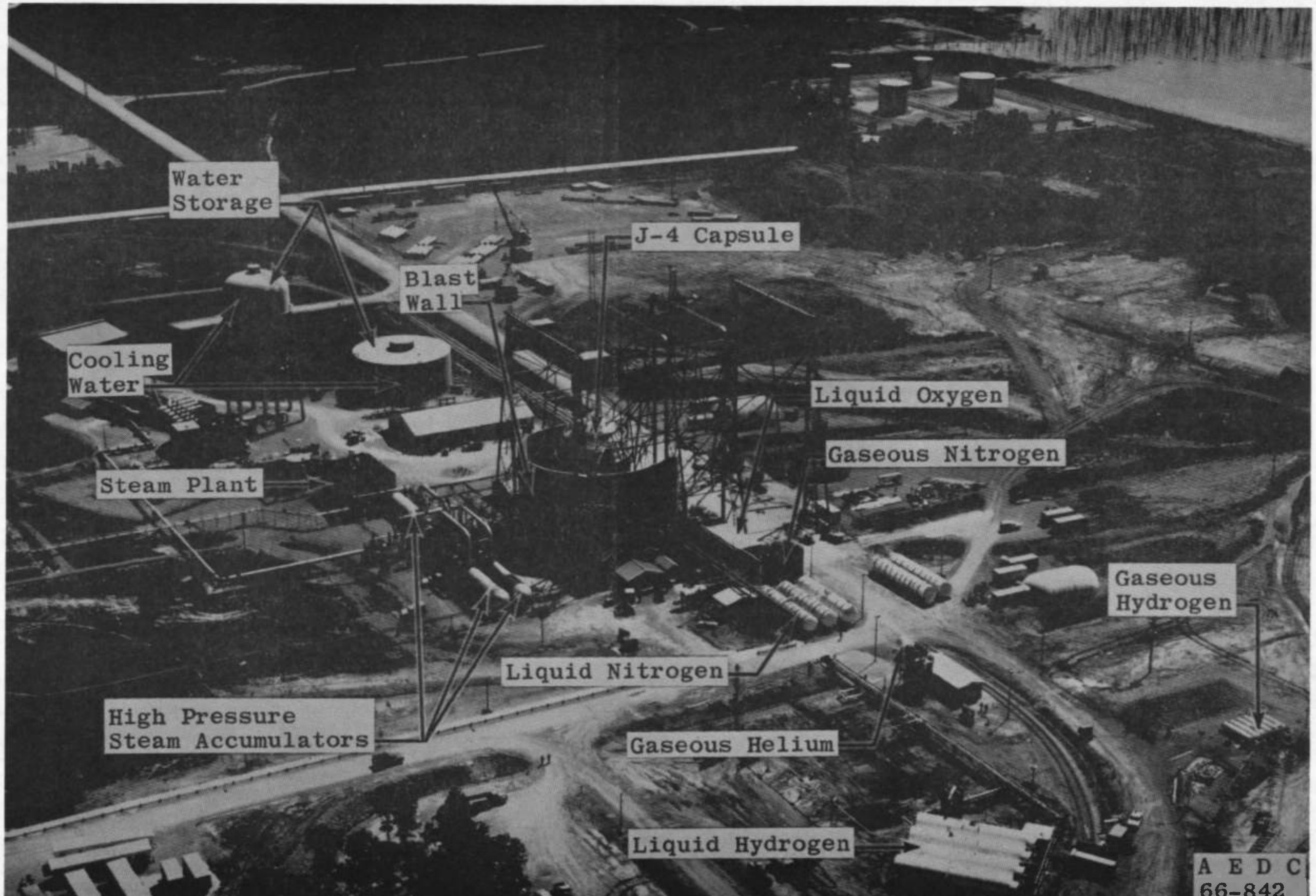


Fig. 1 Test Cell J-4 Complex

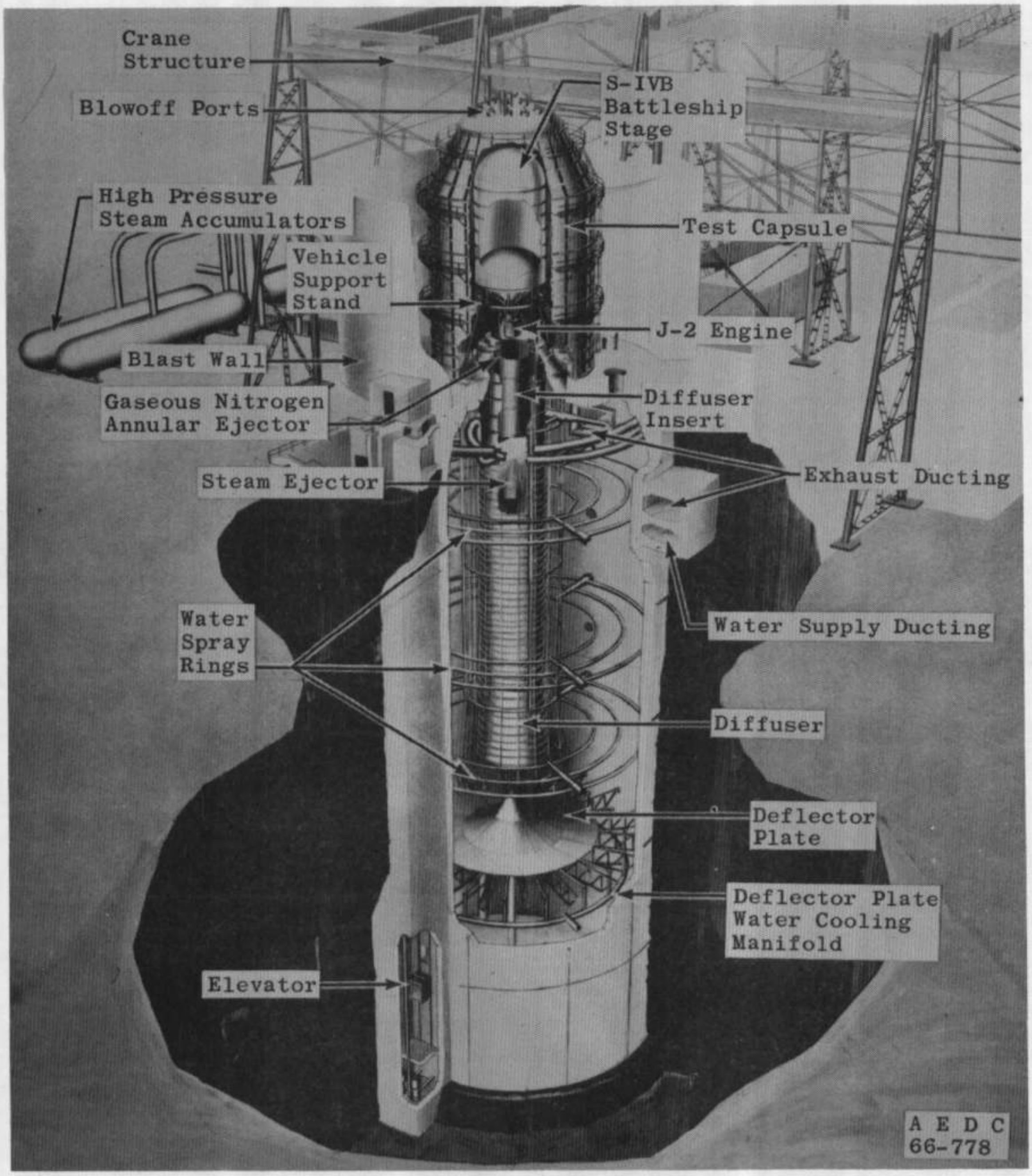


Fig. 2 Test Cell J-4, Artist's Conception

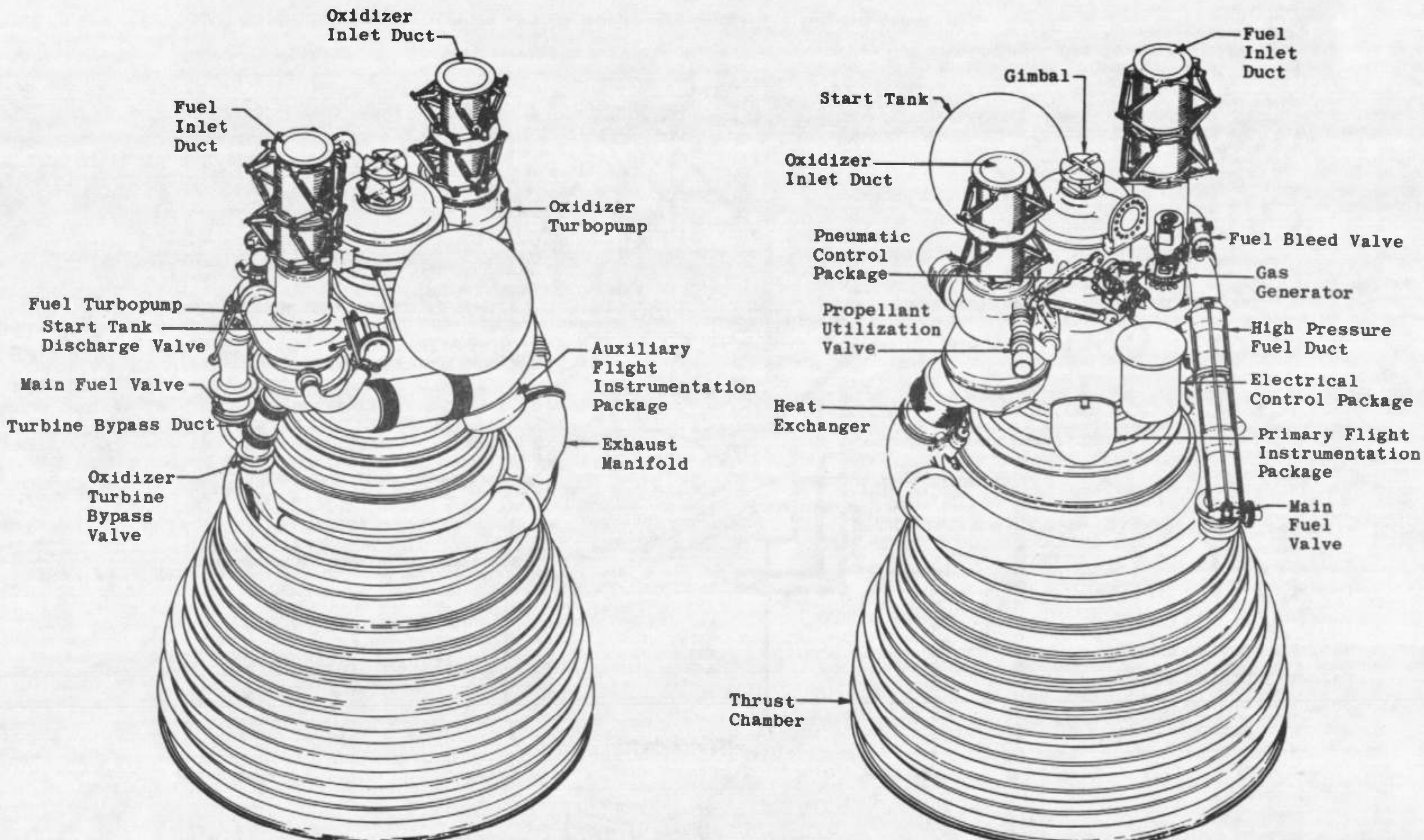


Fig. 3 Engine Details

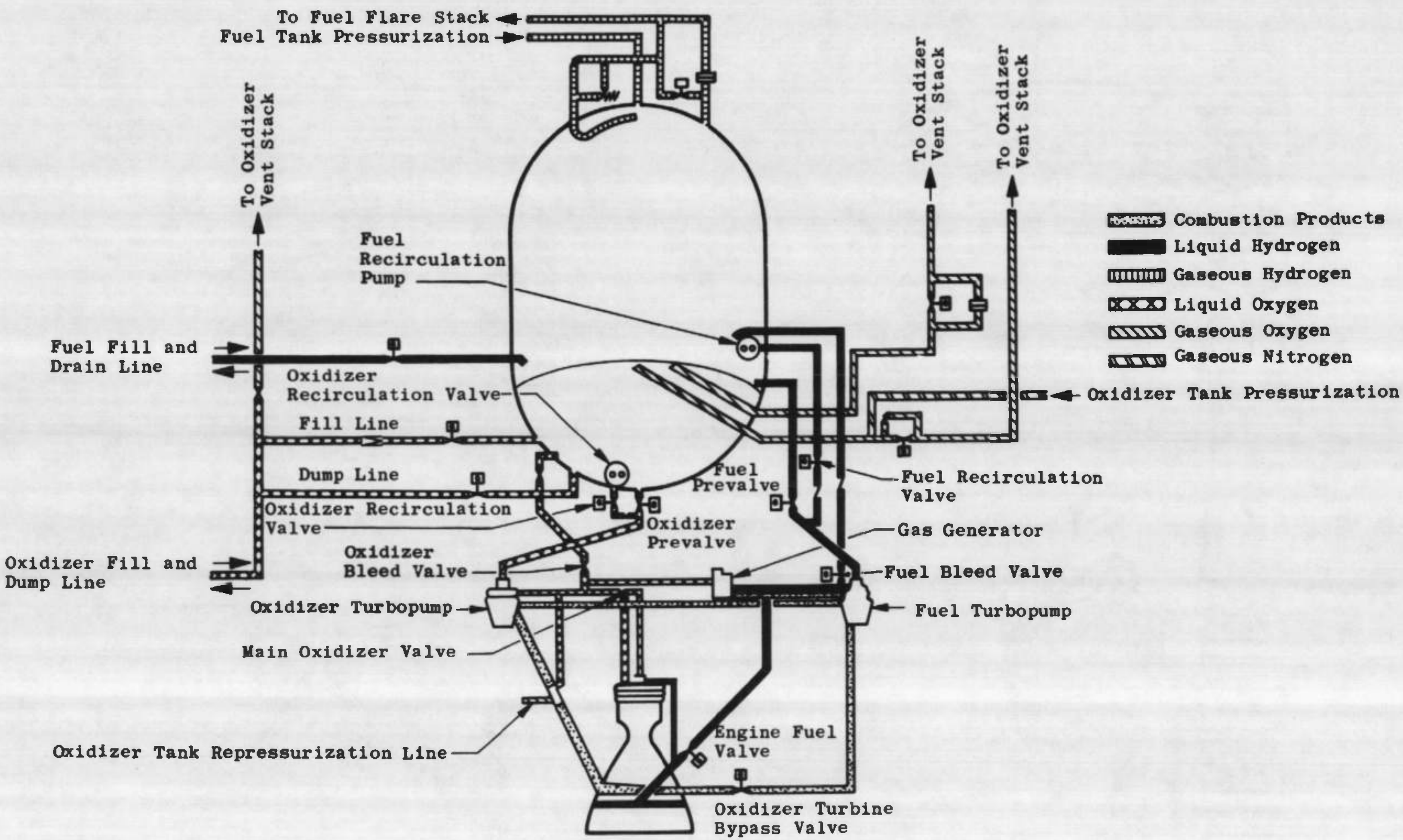


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

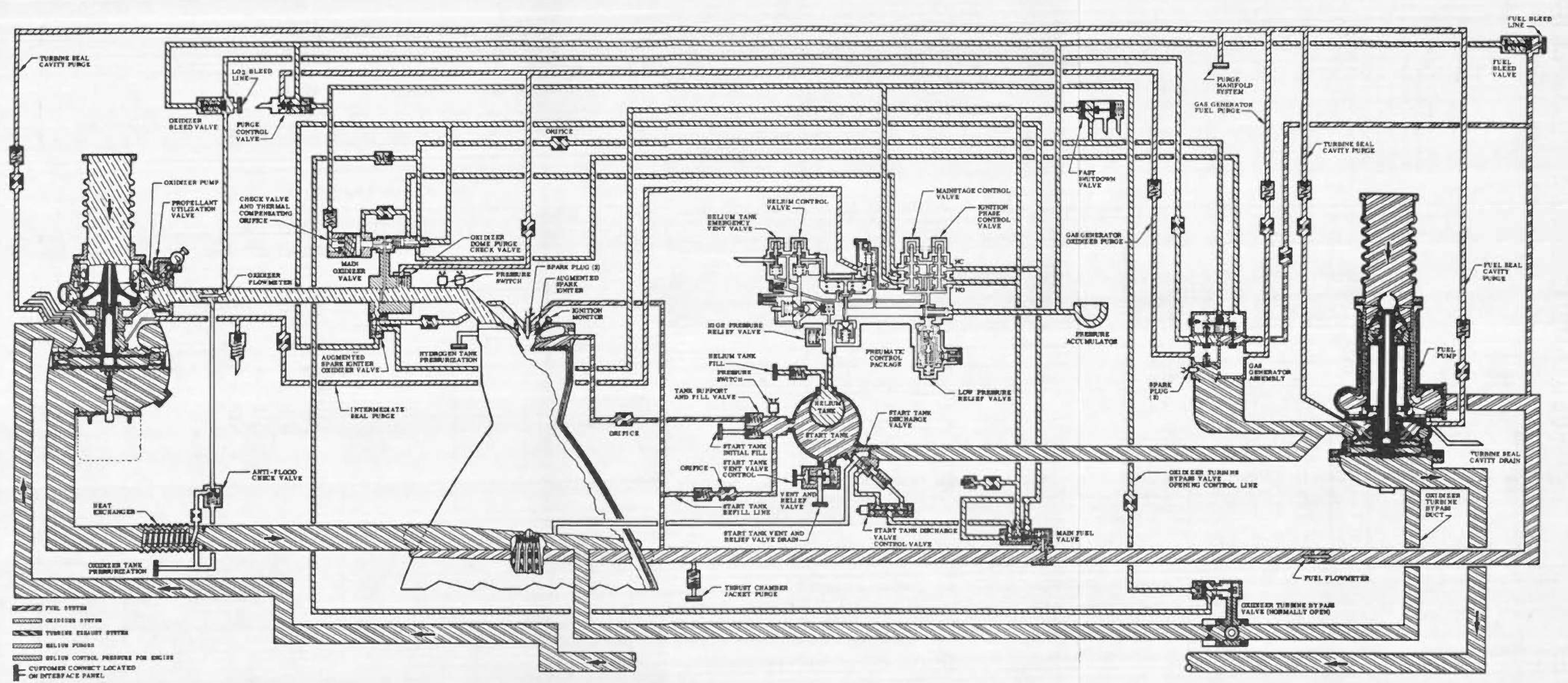


Fig. 5 Engine Schematic

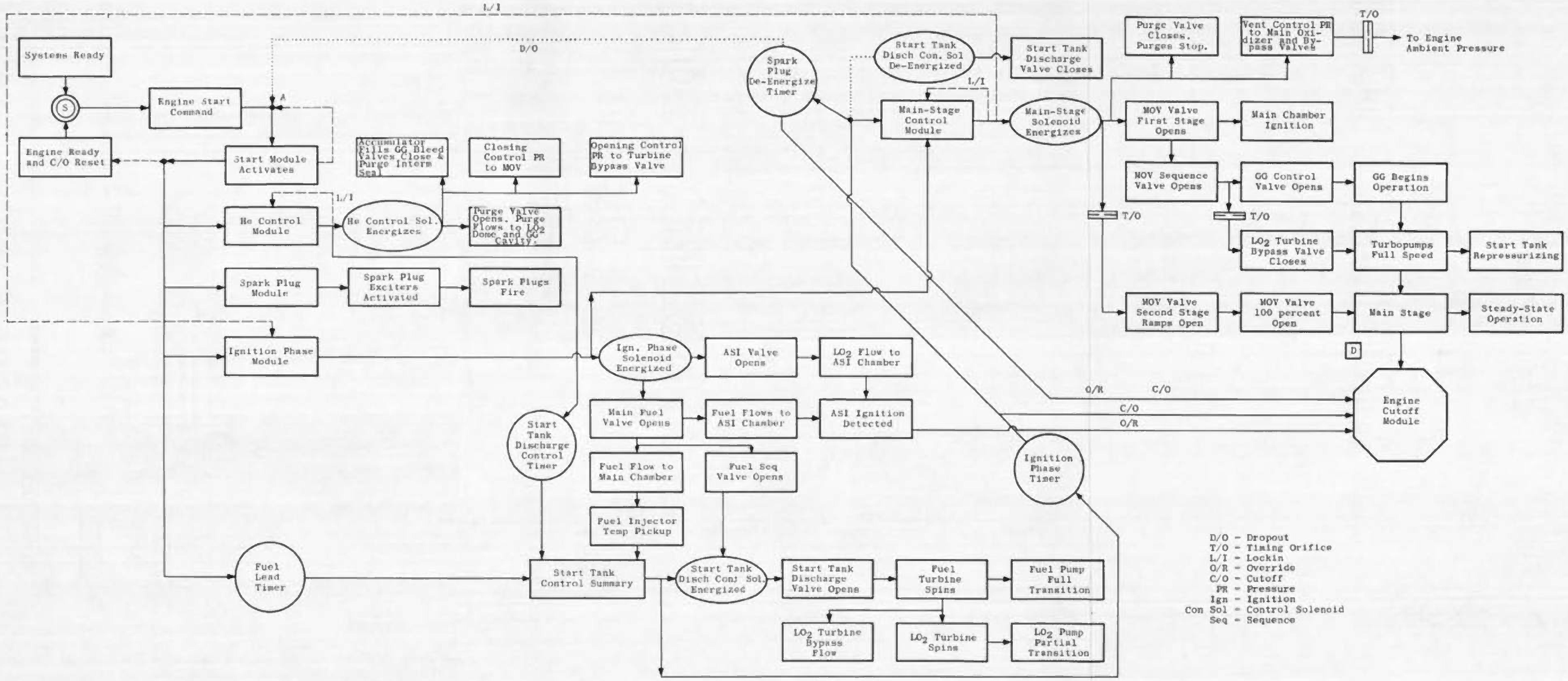
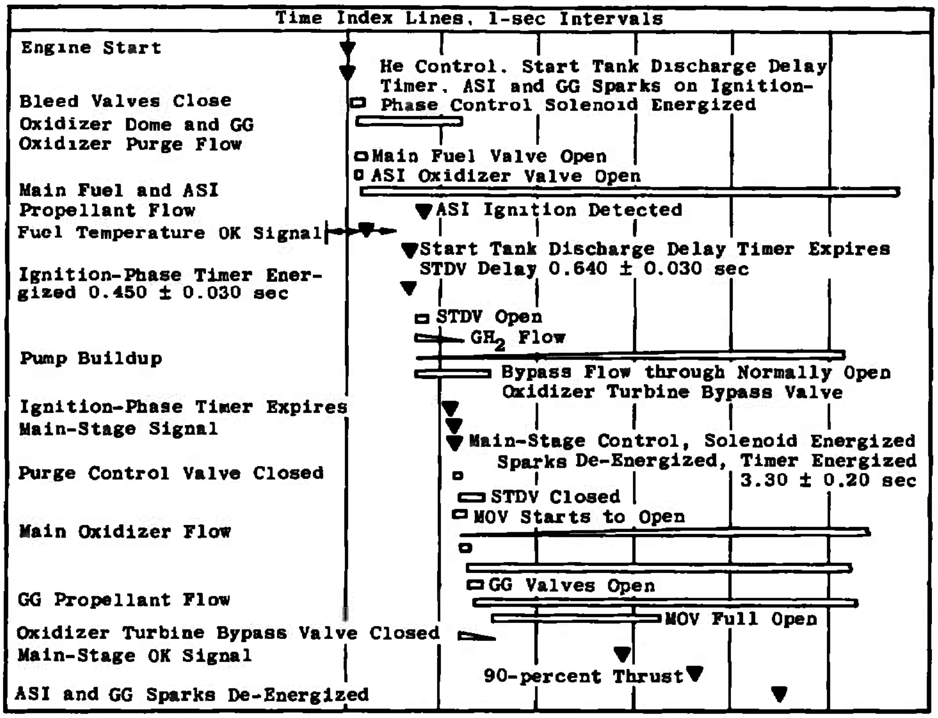
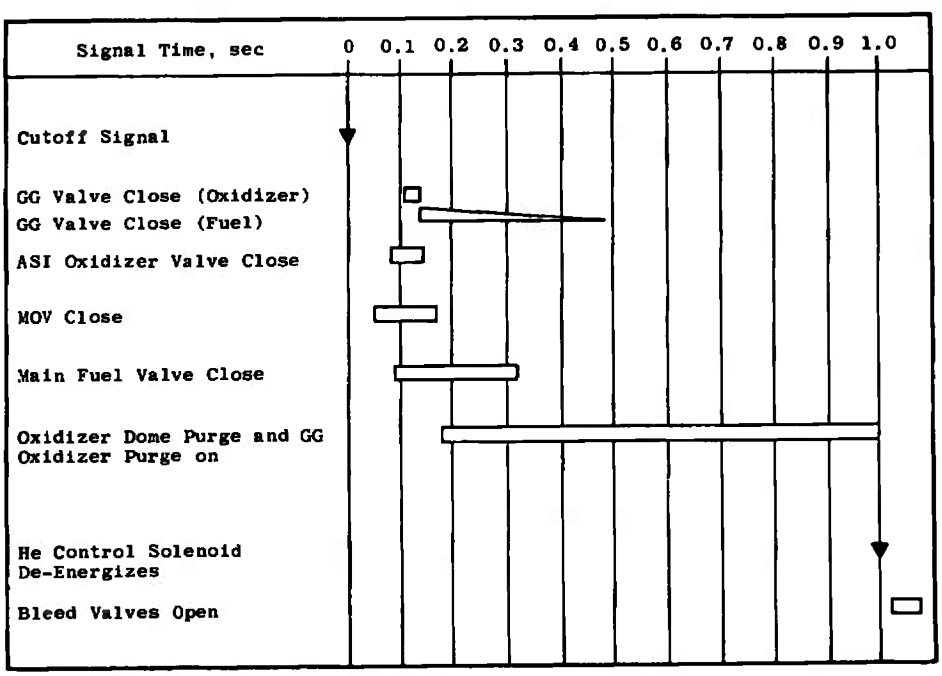


Fig. 6 Engine Start Logic Schematic

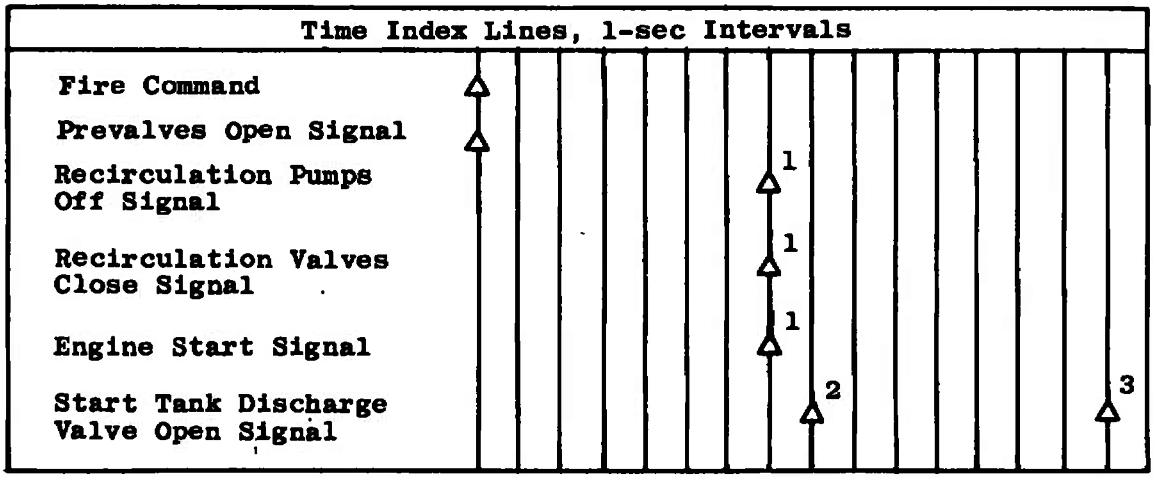


a. Start Sequence



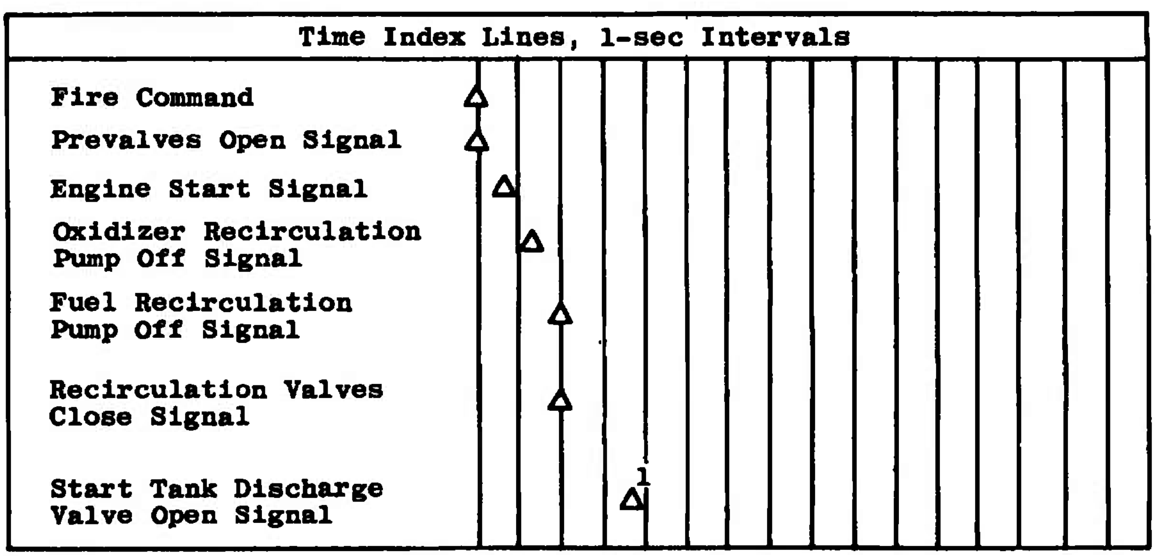
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



[1]Nominal Occurrence Time (Function of Prevalves Opening Time)
[2]One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3]Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

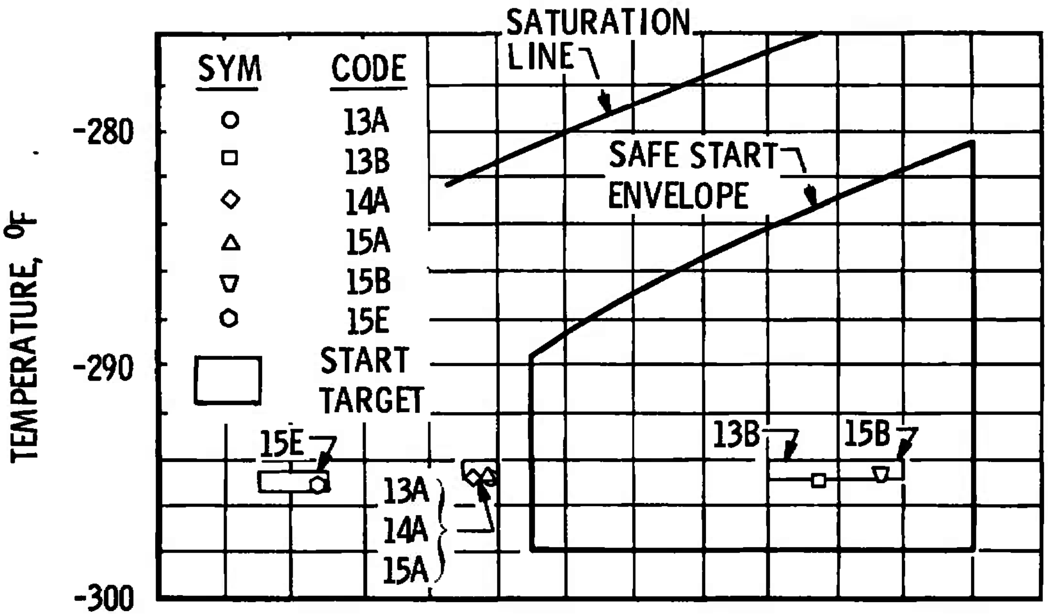
c. "Normal" Start Sequence



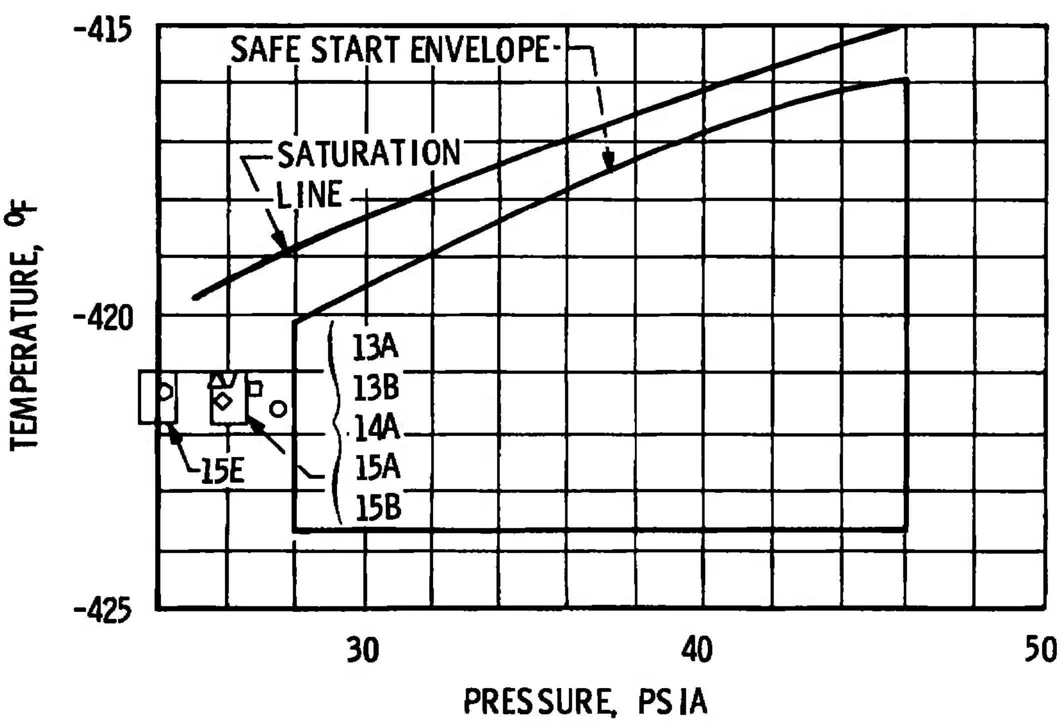
[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. "Auxiliary" Start Sequence

Fig. 7 Concluded

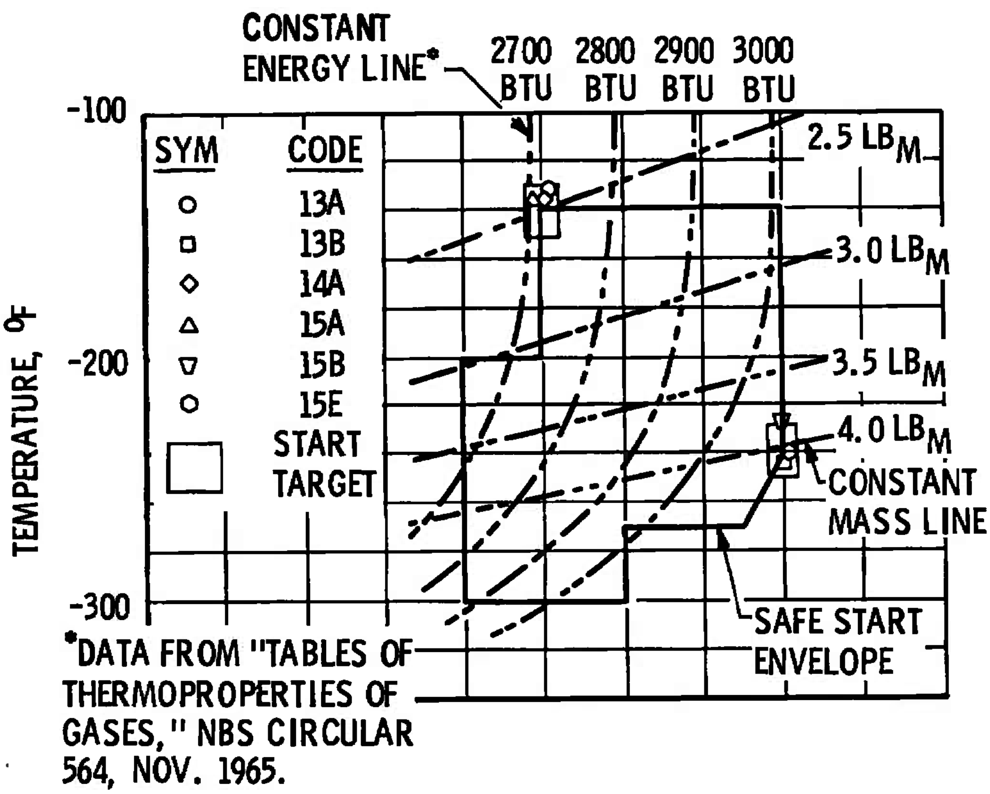


a. Oxidizer Pump Inlet

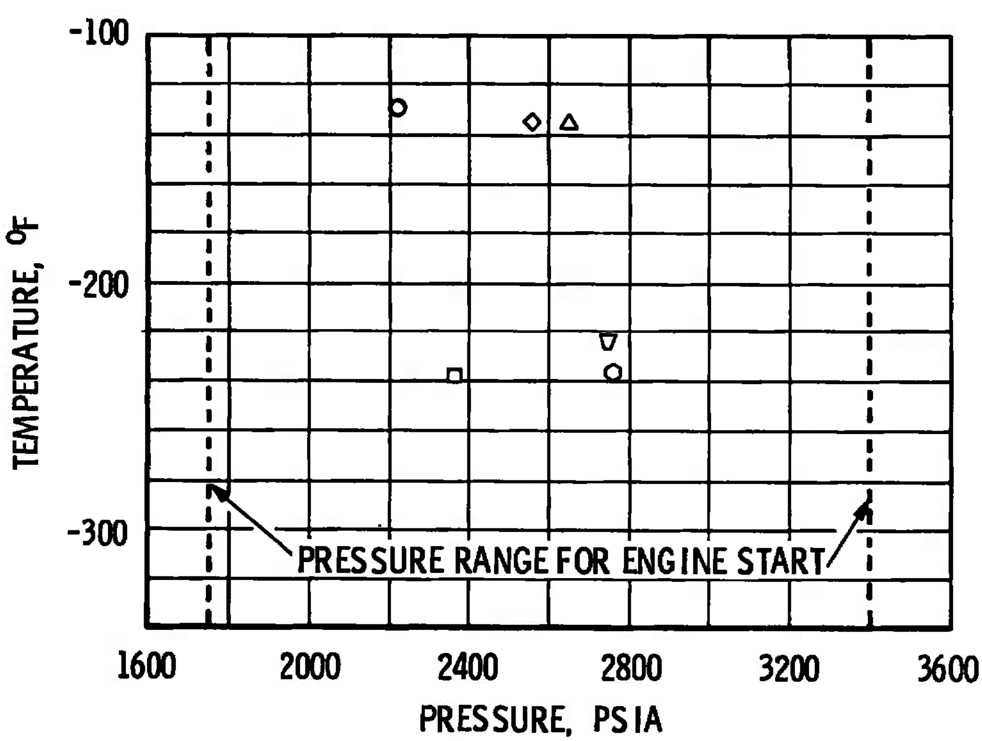


b. Fuel Pump Inlet

Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank

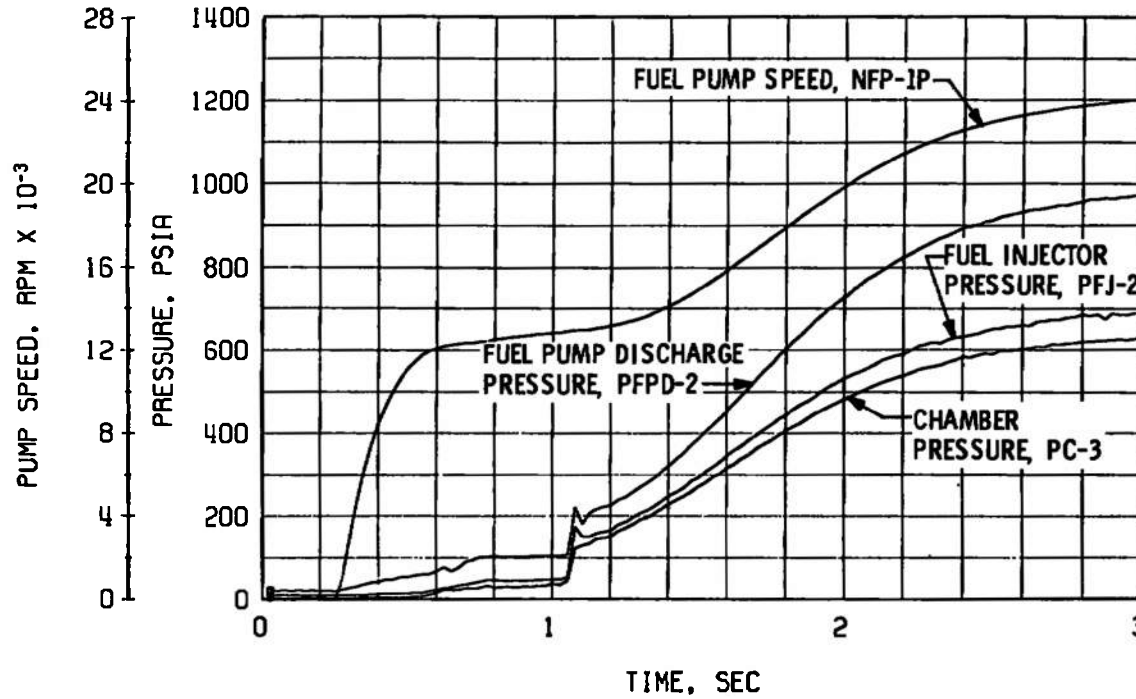


c. Start Tank

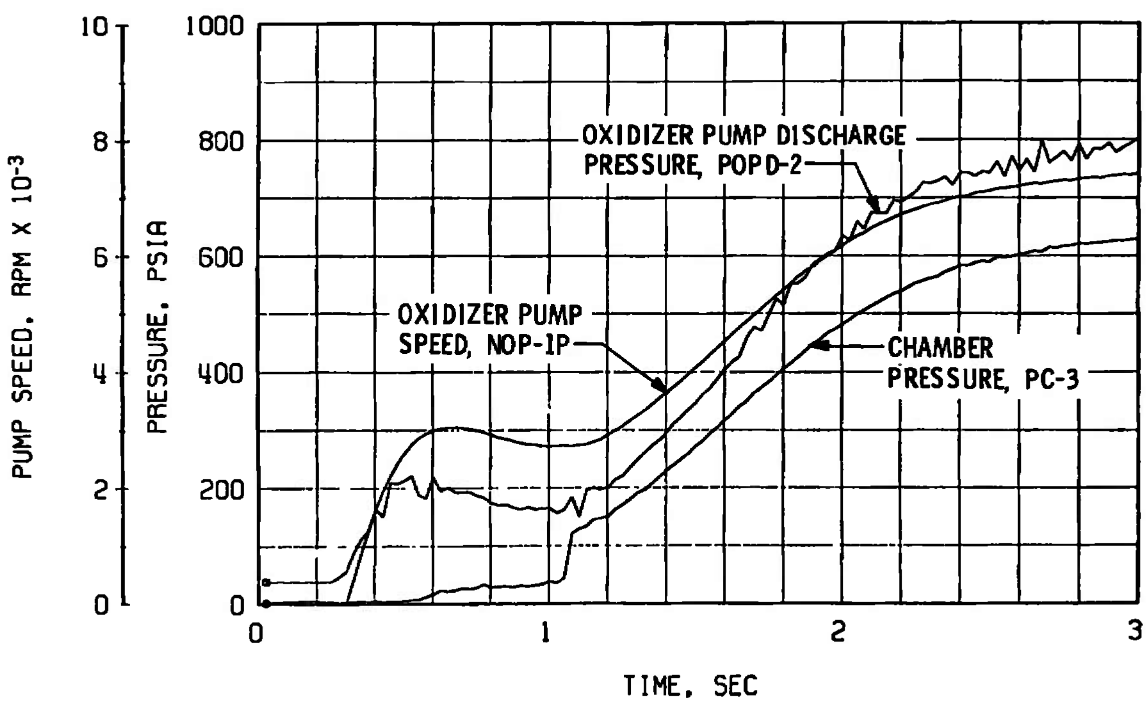


d. Helium Tank

Fig. 8 Concluded

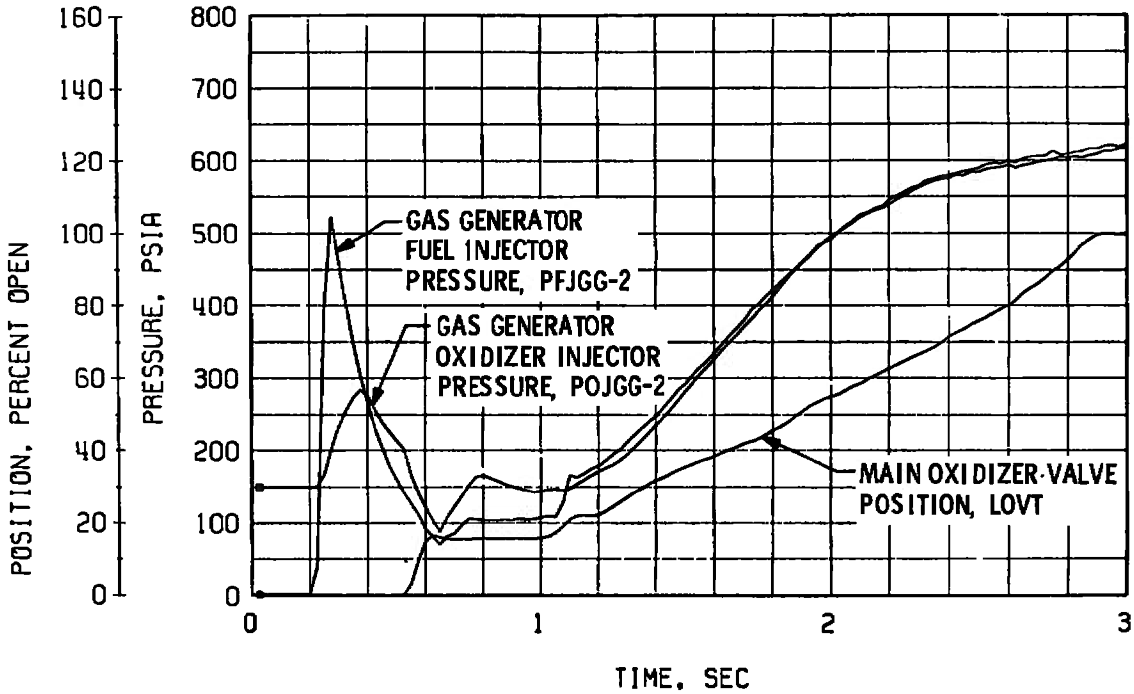


a. Thrust Chamber Fuel System, Start

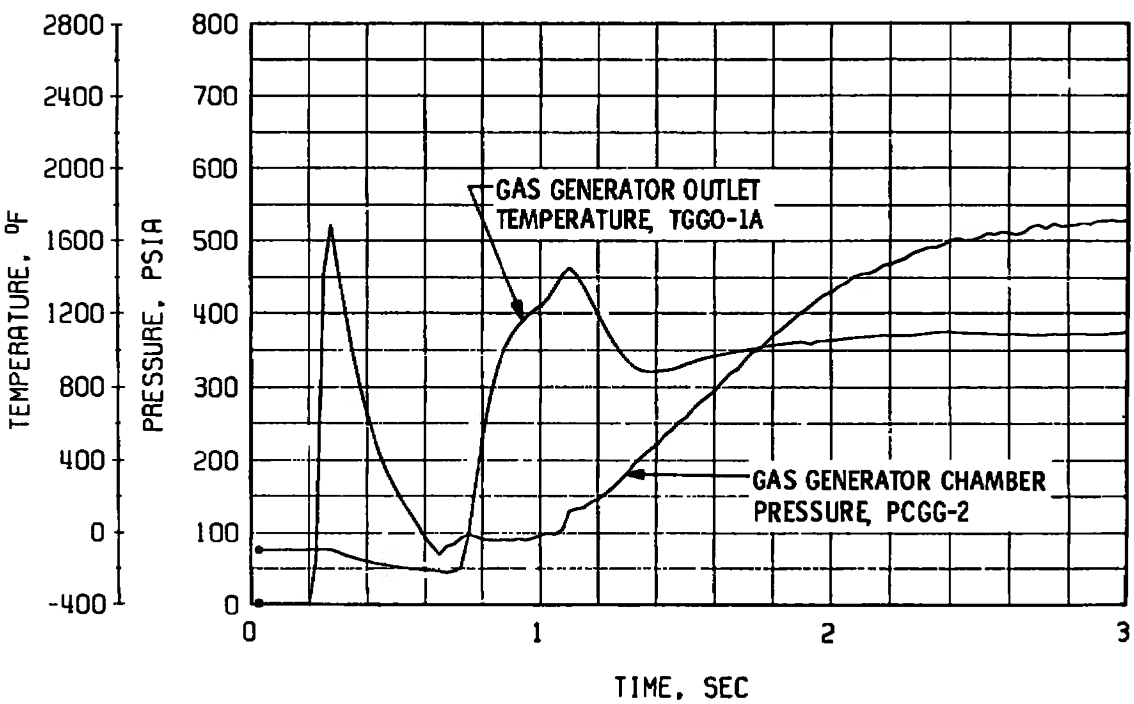


b. Thrust Chamber Oxidizer System, Start

Fig. 9 Engine Start Transient Operation, Firing 13A

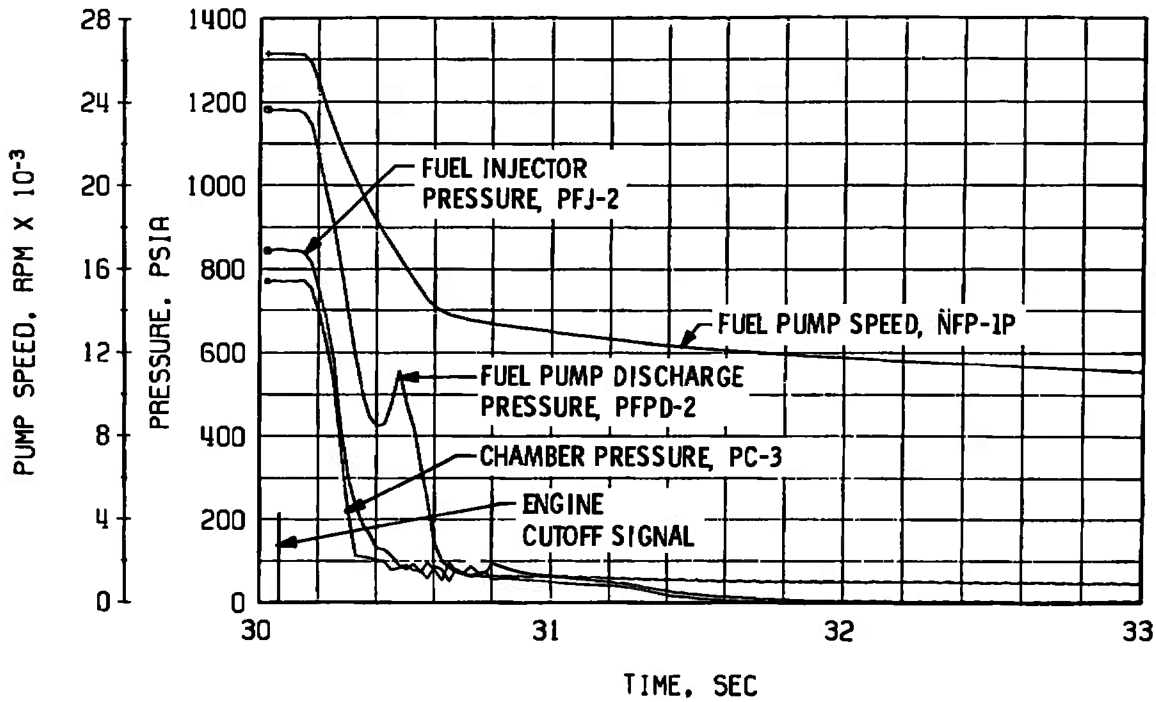


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

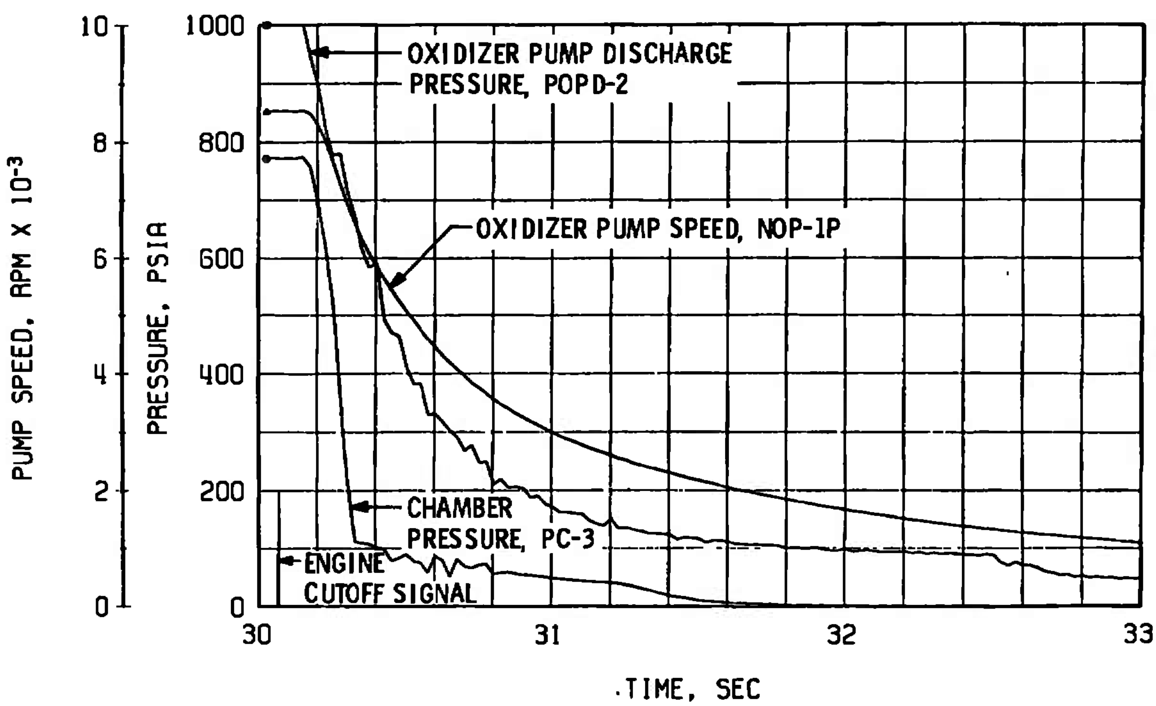


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 9 Concluded

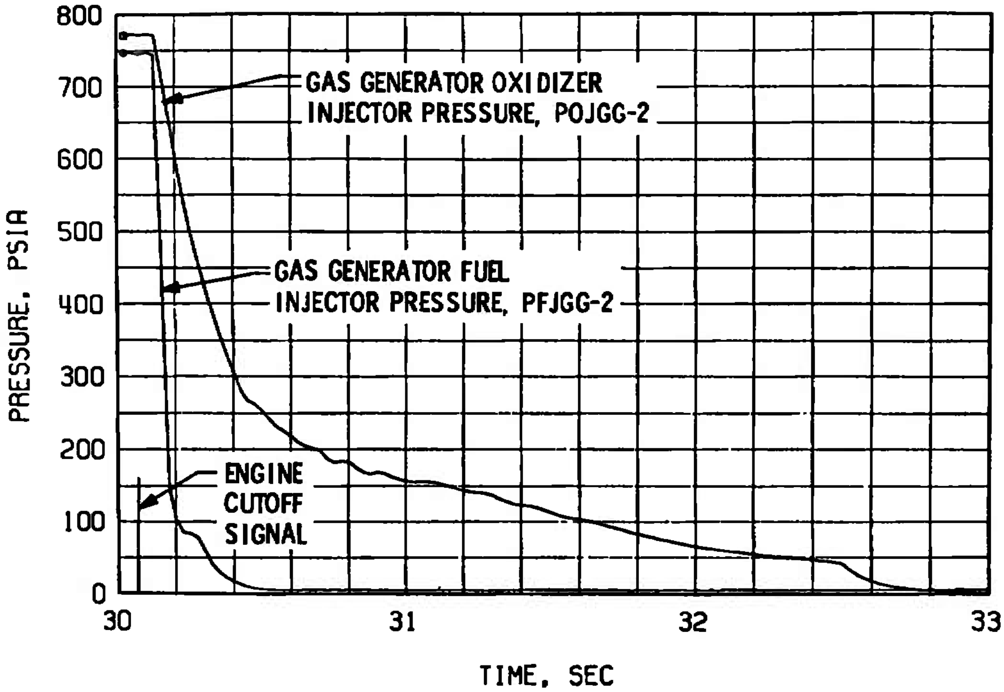


a. Thrust Chamber Fuel System, Shutdown

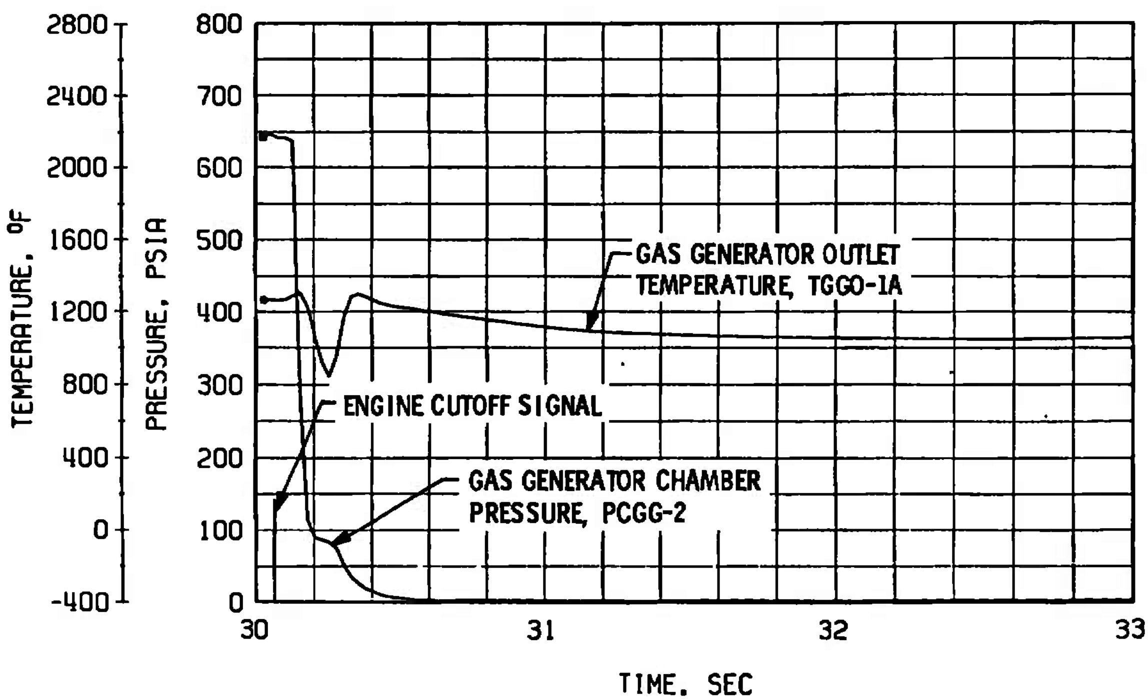


b. Thrust Chamber Oxidizer System, Shutdown

Fig. 10 Engine Shutdown Transient Operation, Firing 13A



c. Gas Generator Injector Pressures, Shutdown



d. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 10 Concluded

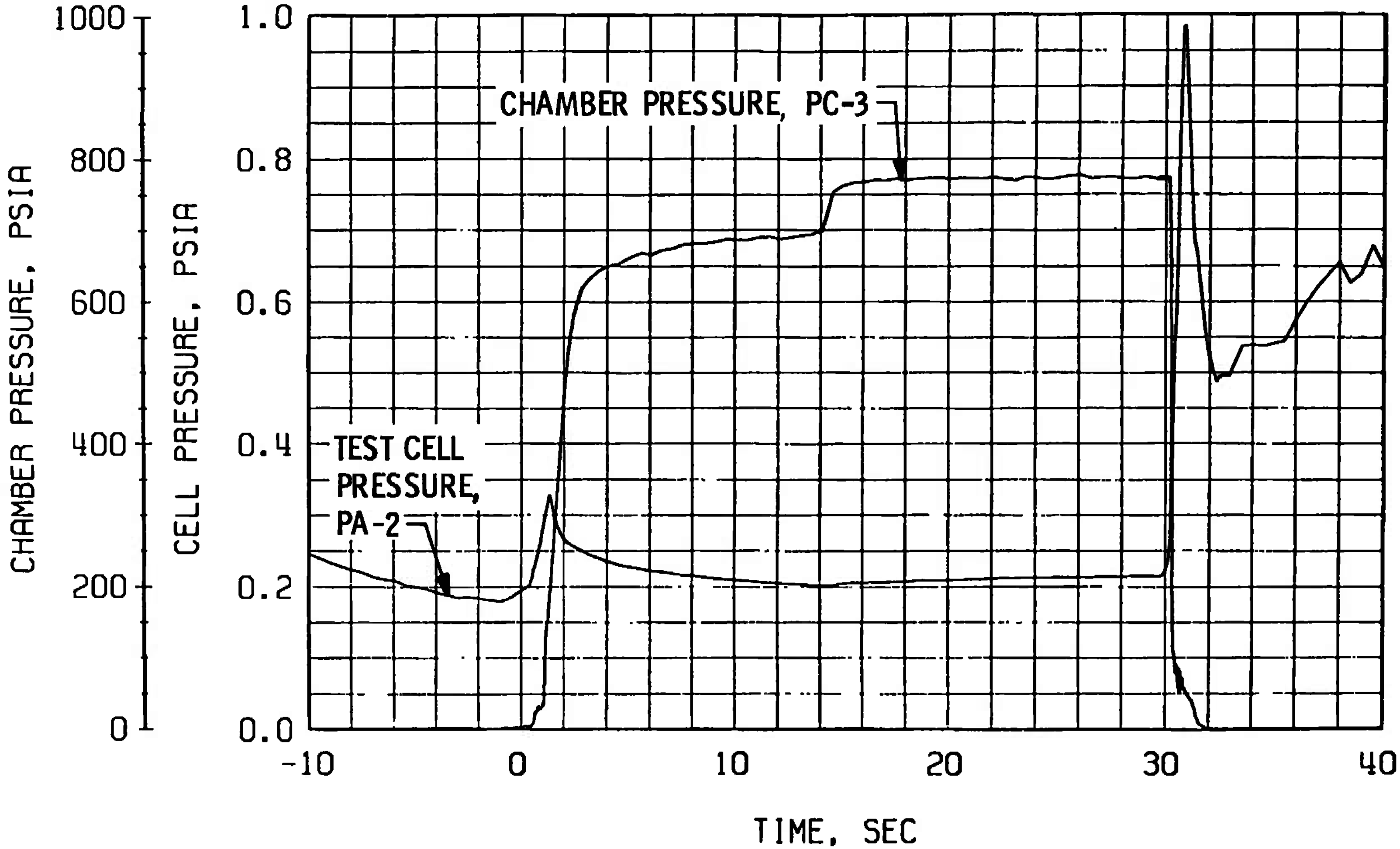
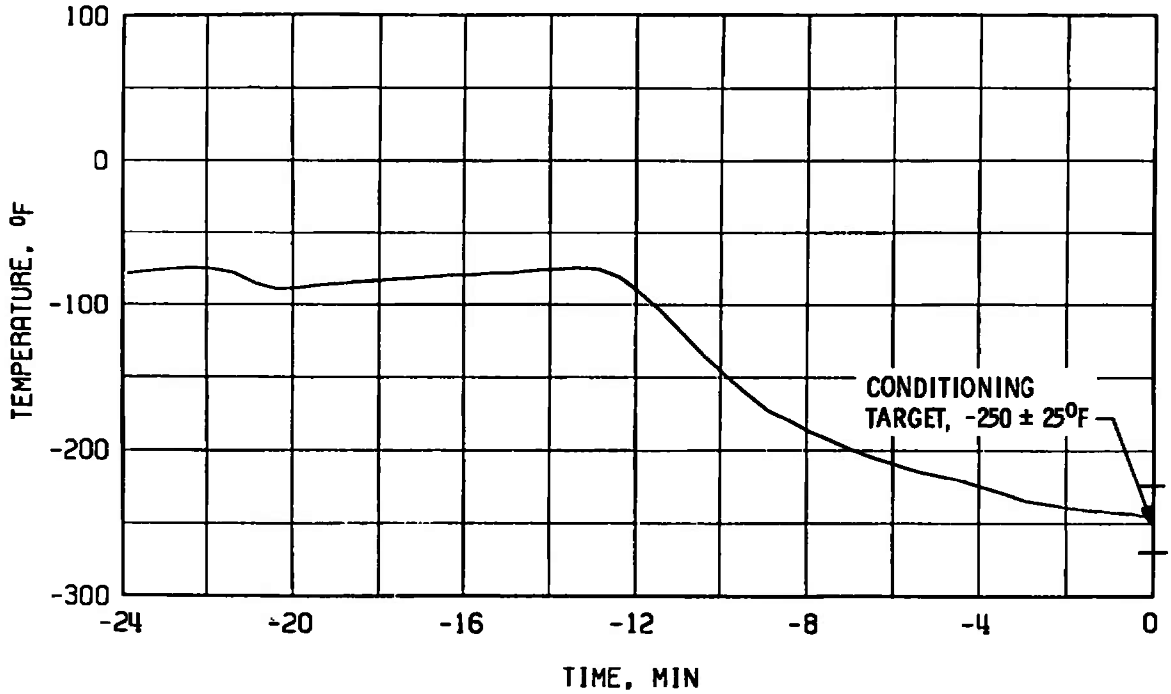
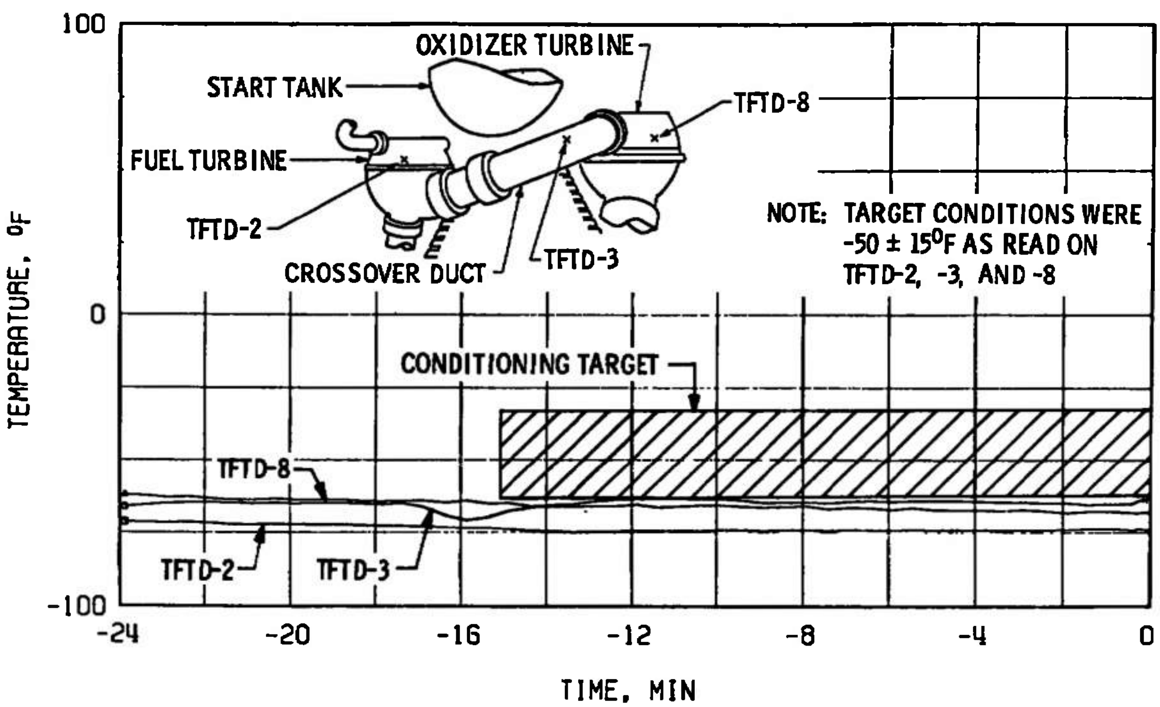


Fig. 11 Engine Ambient and Combustion Chamber Pressures, Firing 13A

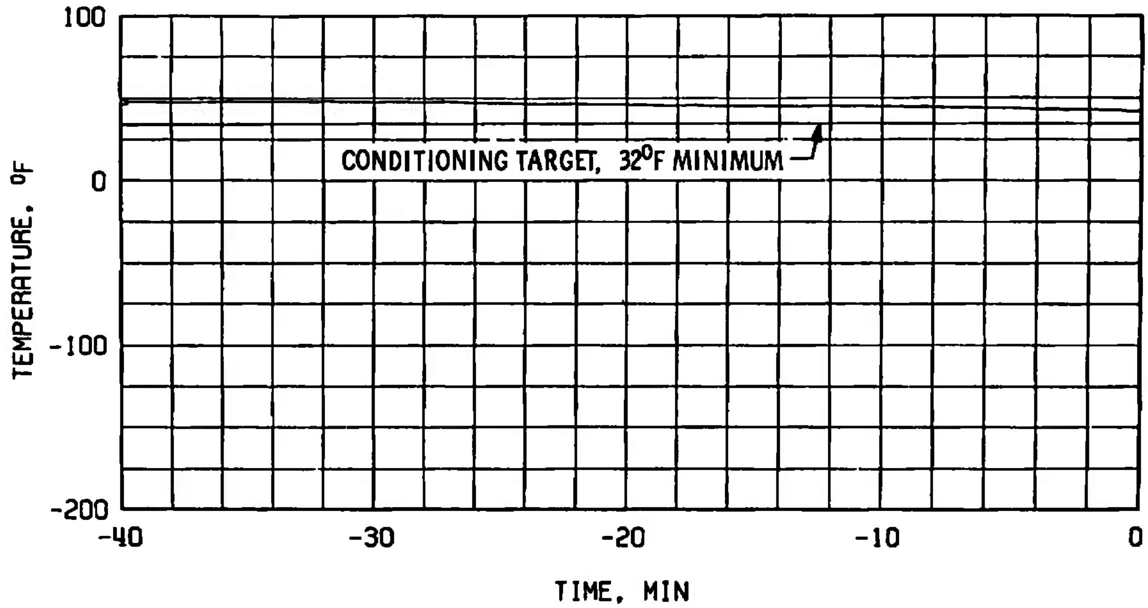


a. Thrust Chamber Throat, TTC-1P

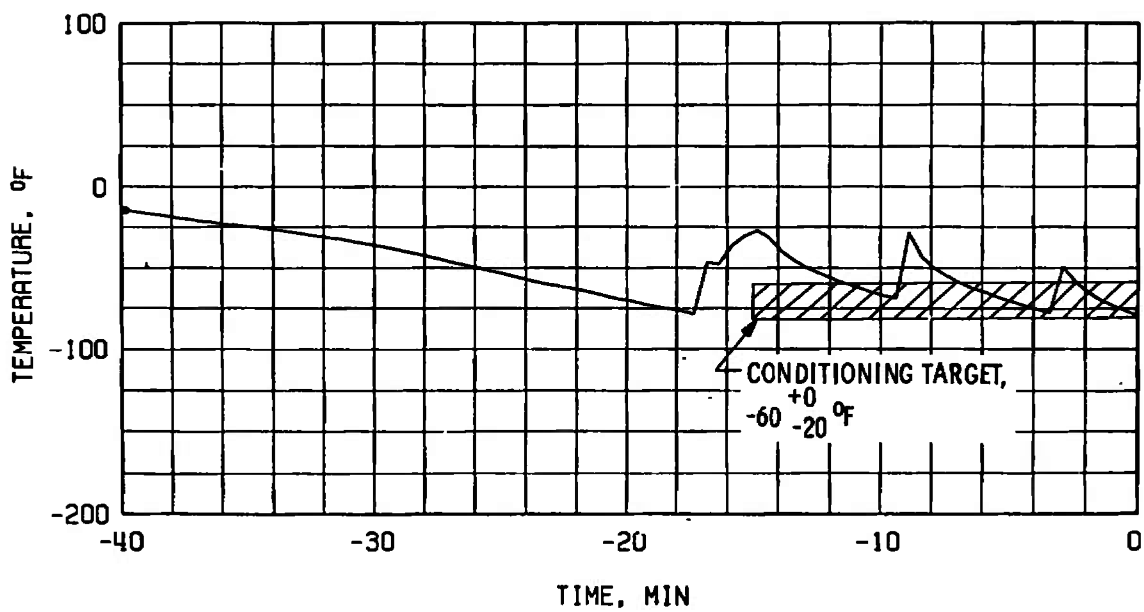


b. Crossover Duct, TFTD

Fig. 12 Thermal Conditioning History of Engine Components, Firing 13A



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 12 Concluded

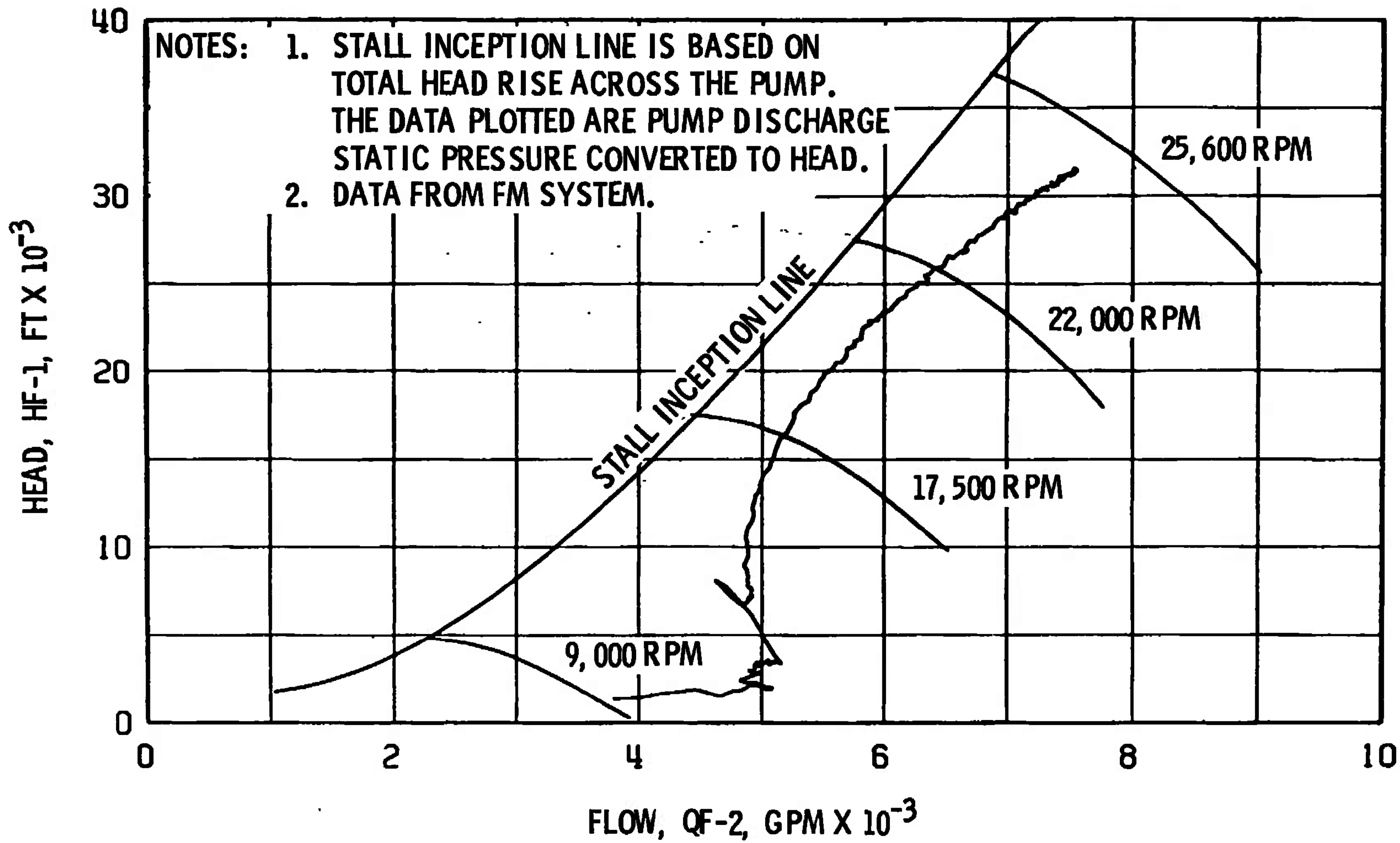


Fig. 13 Fuel Pump Start Transient Performance, Firing 13A

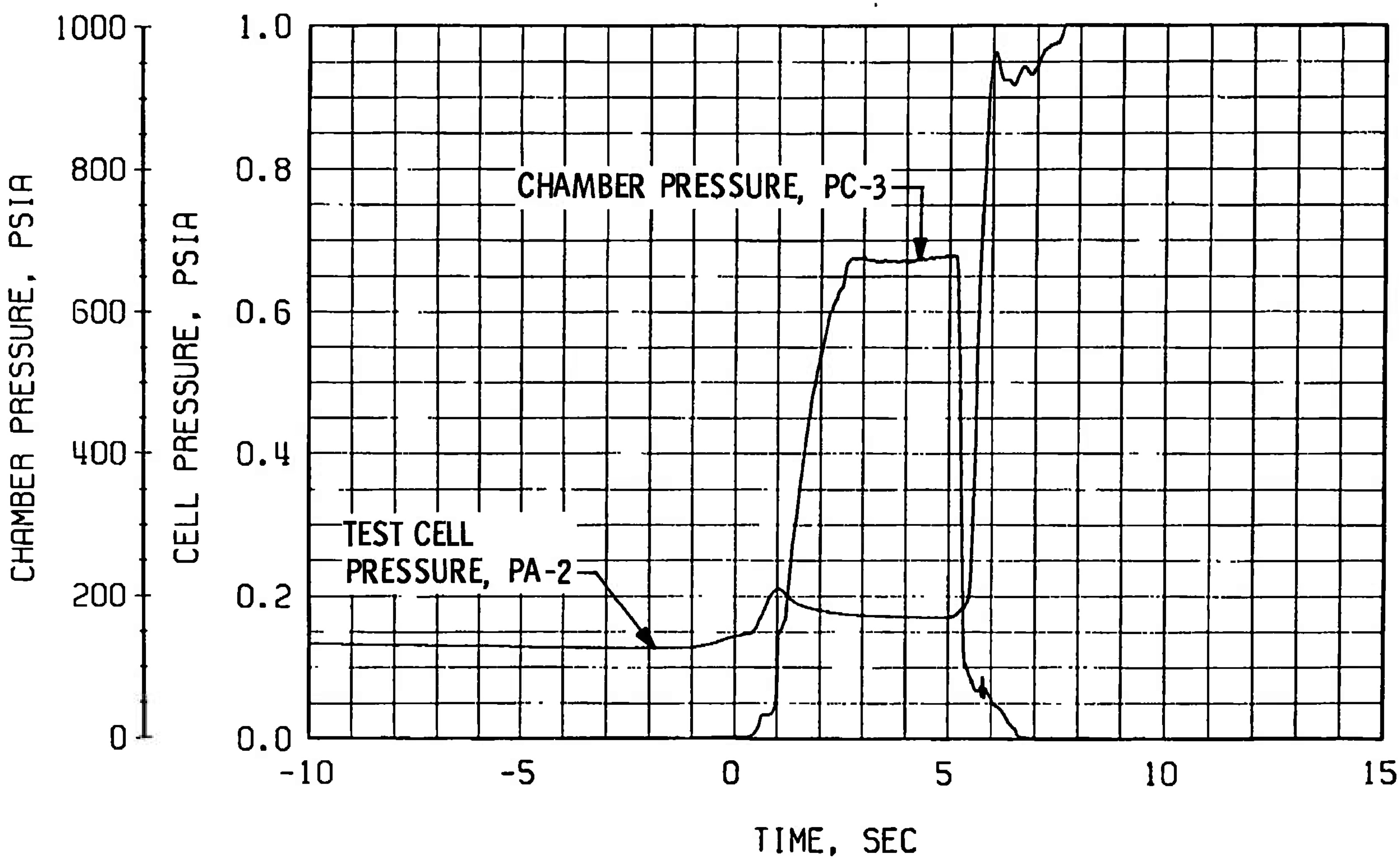
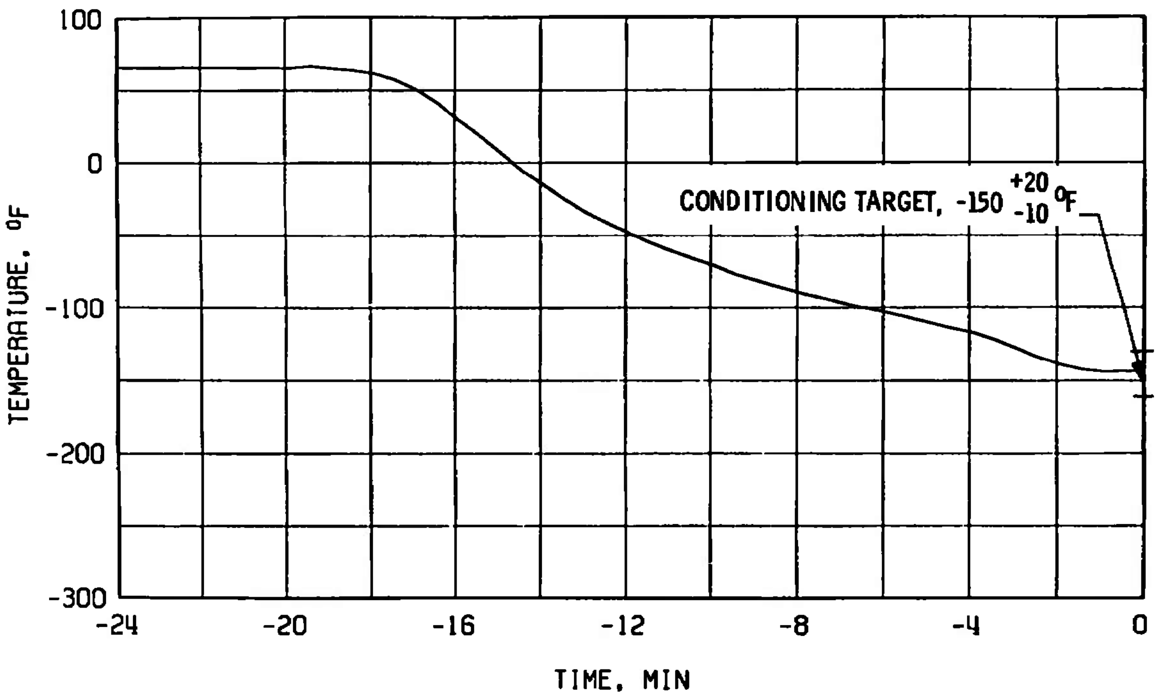
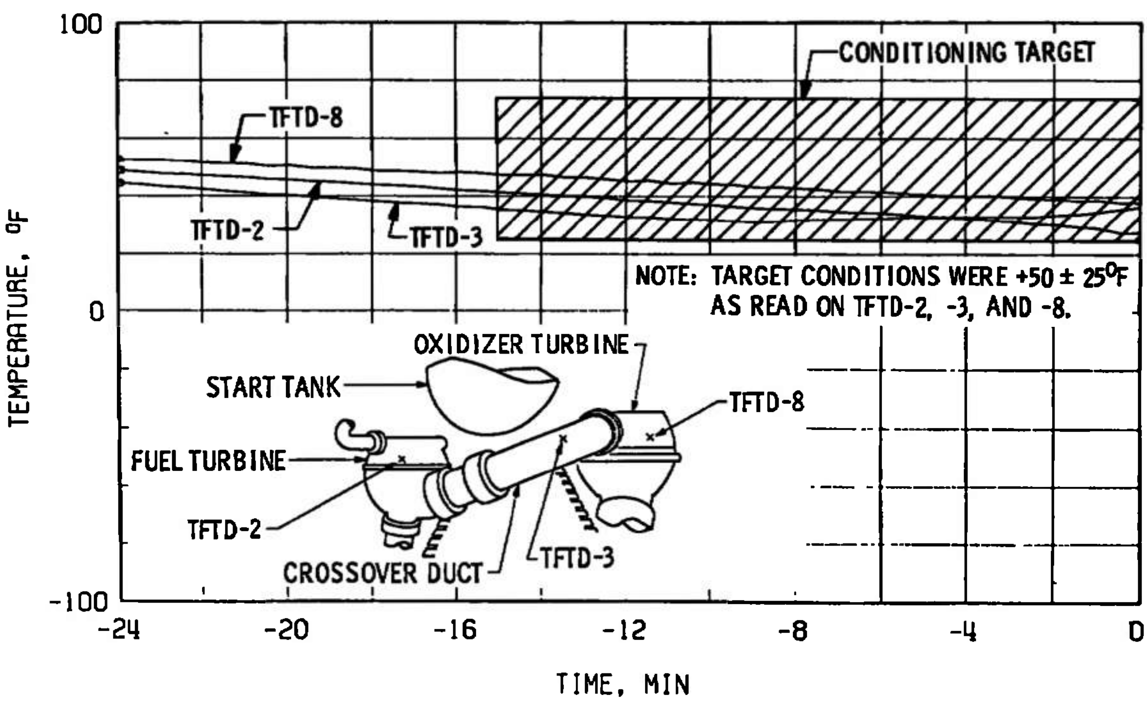


Fig. 14 Engine Ambient and Combustion Chamber Pressures, Firing 13B

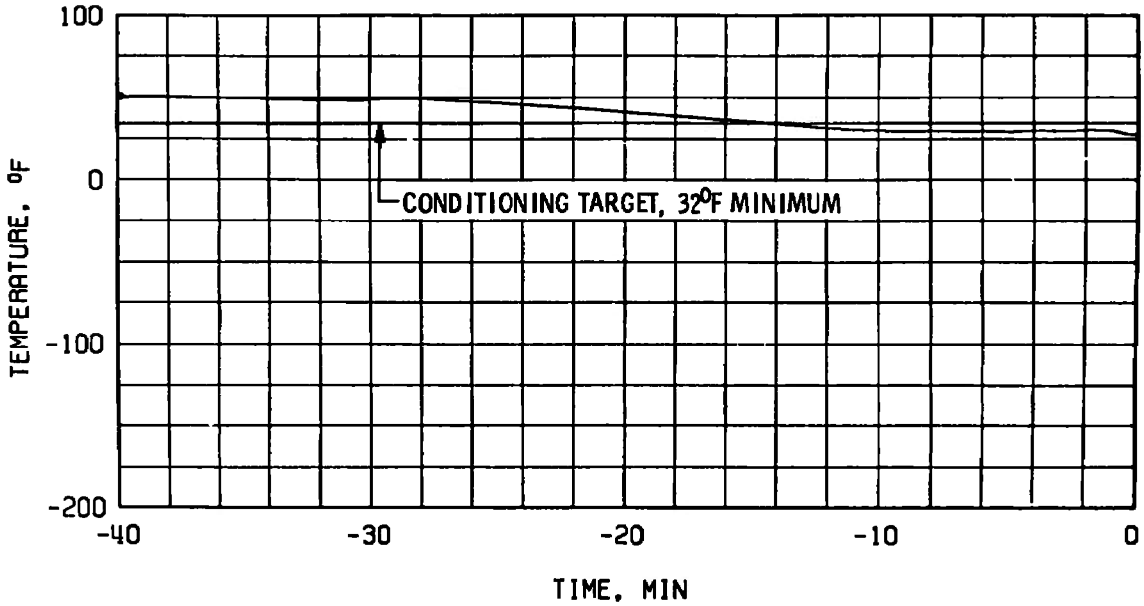


a. Thrust Chamber Throat, TTC-1P

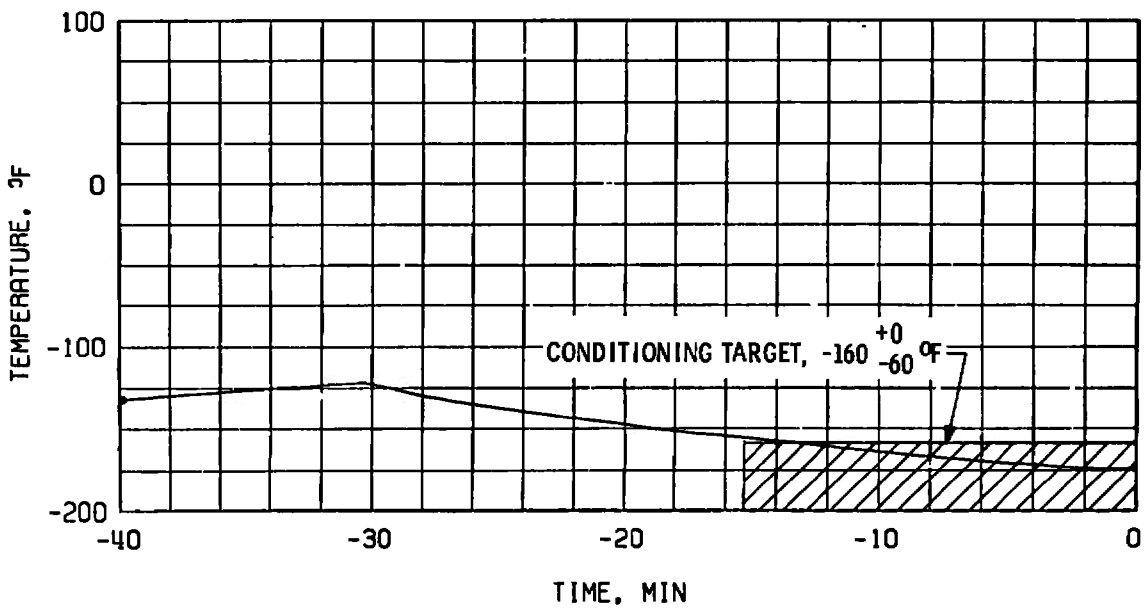


b. Crossover Duct, TFTD

Fig 15 Thermal Conditioning History of Engine Components, Firing 13B

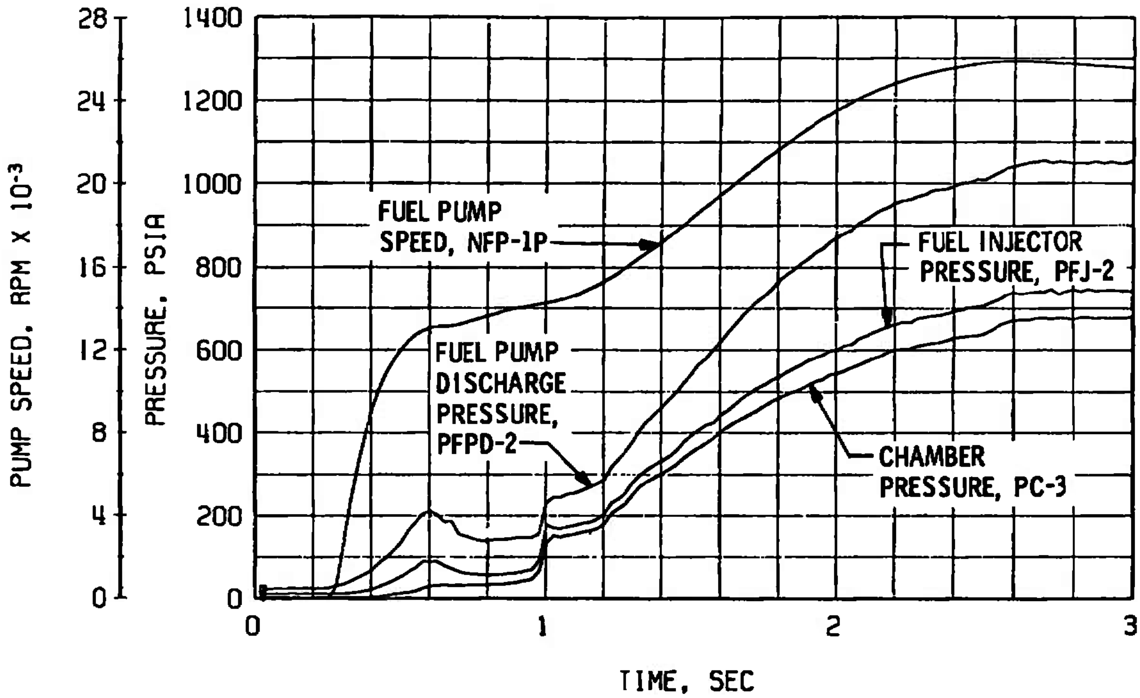


c. Start Tank Discharge Valve, TSTDVOC

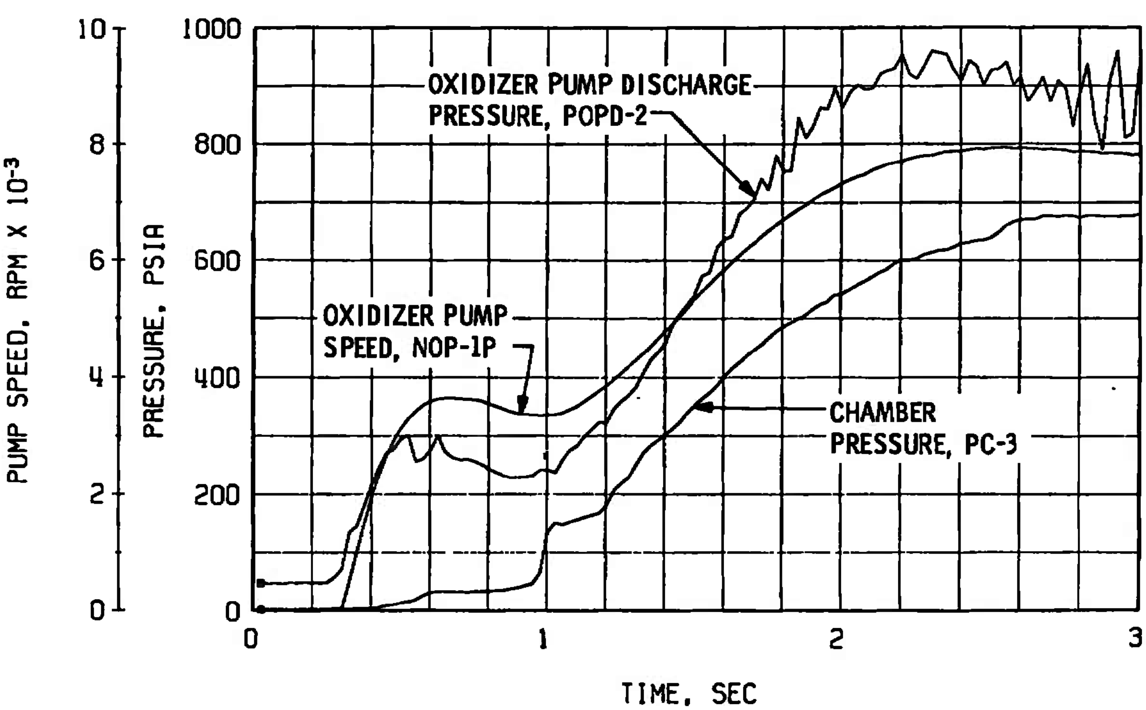


d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 15 Concluded

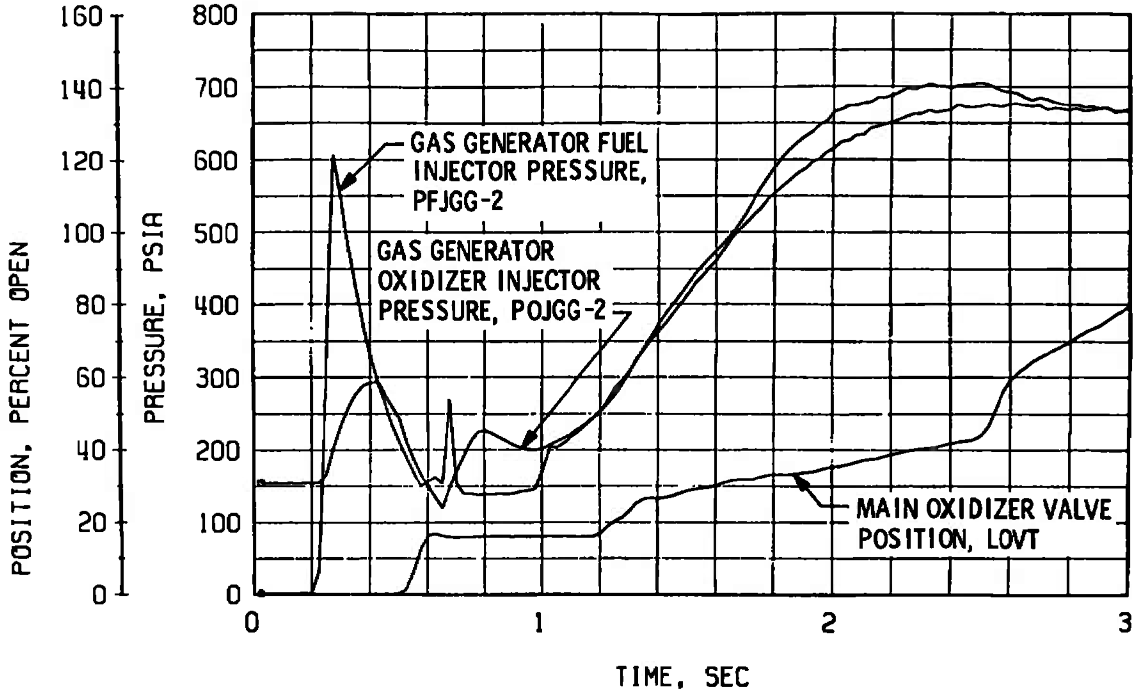


a. Thrust Chamber Fuel System, Start

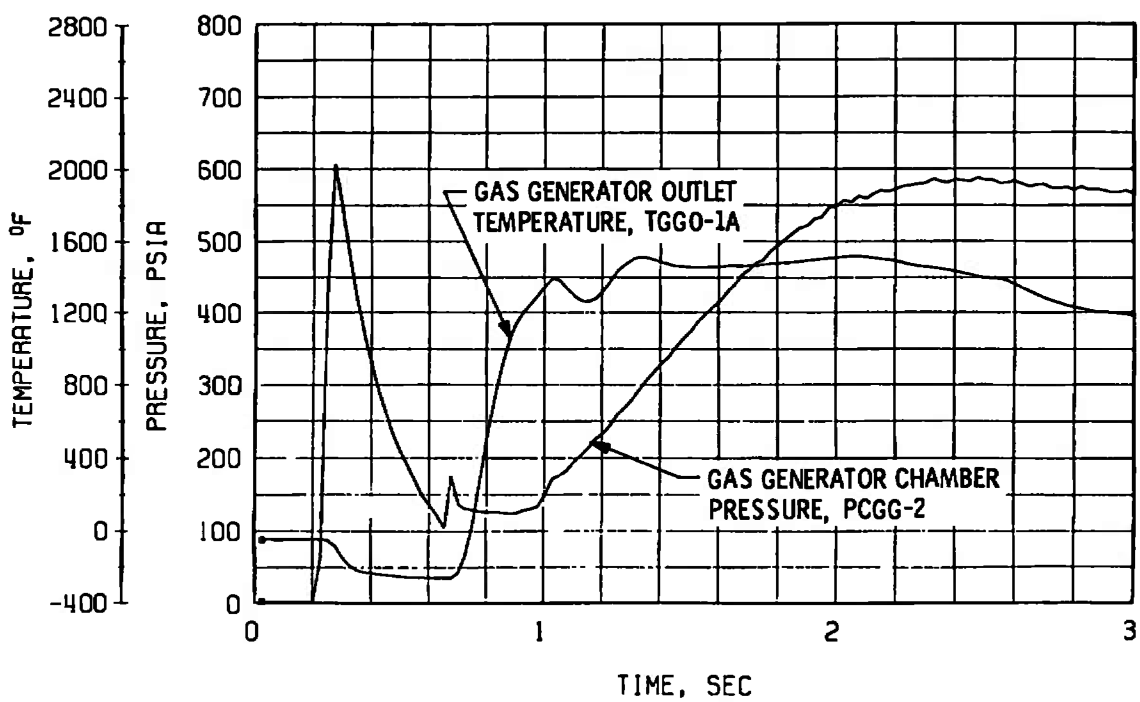


b. Thrust Chamber Oxidizer System, Start

Fig. 16 Engine Start Transient Operation, Firing 13B

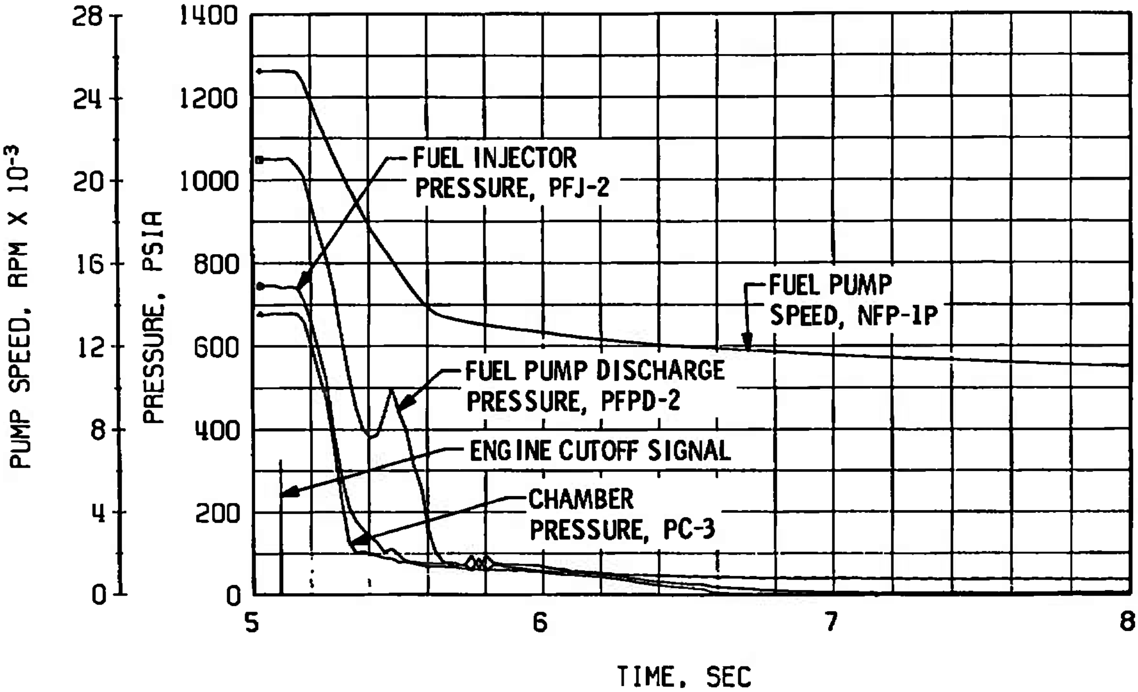


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

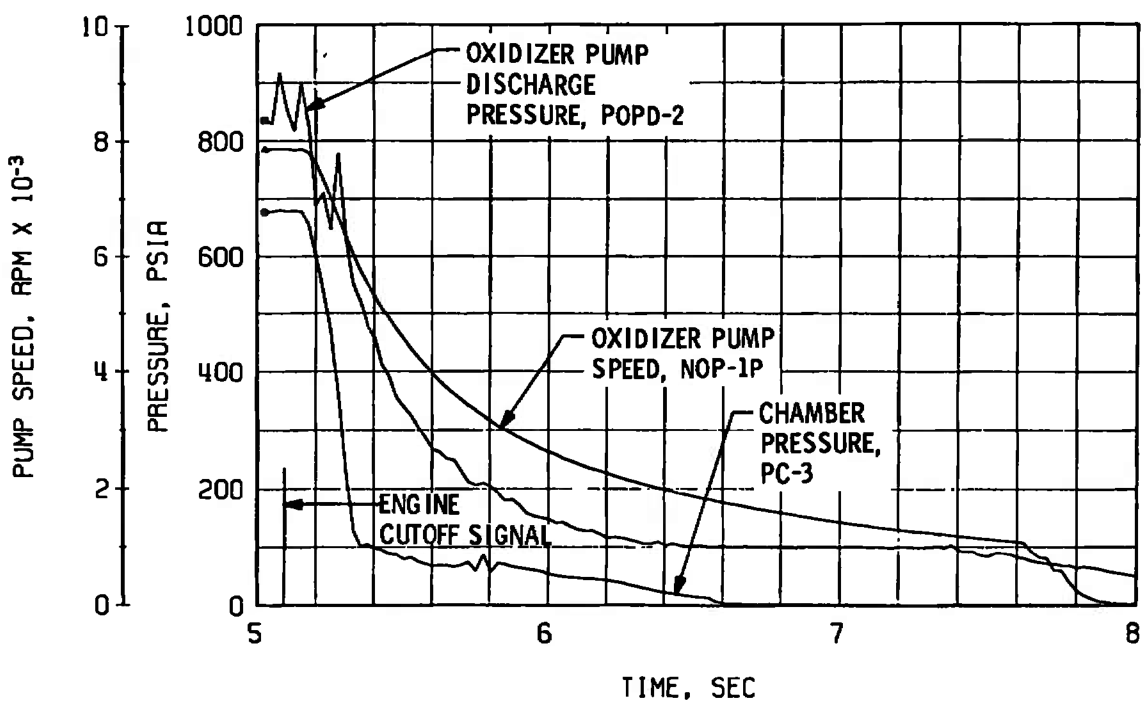


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 16 Concluded

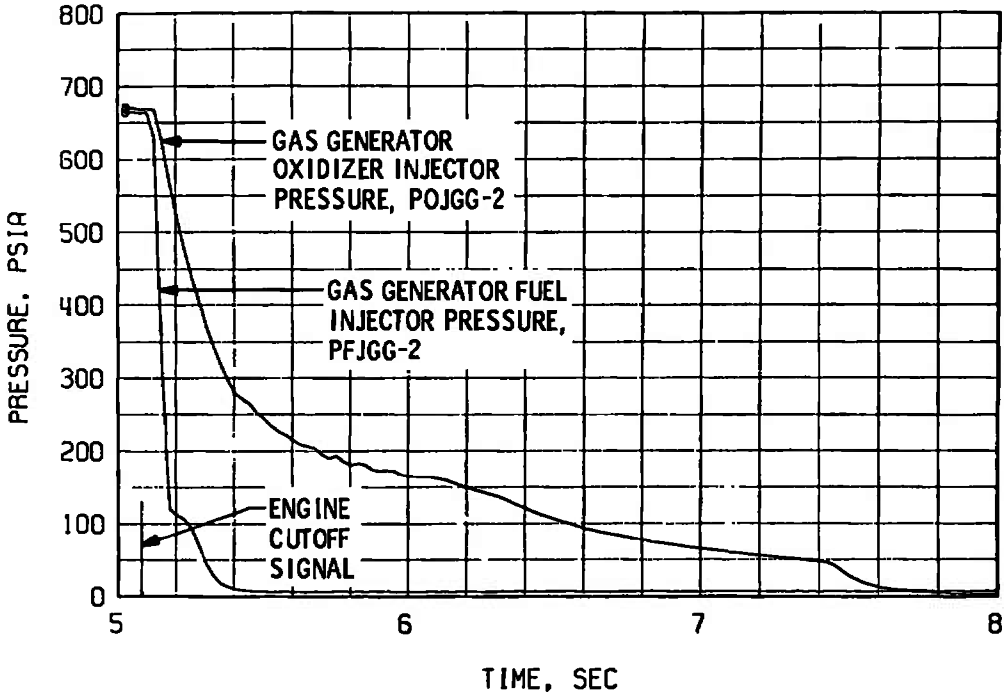


a. Thrust Chamber Fuel System, Shutdown

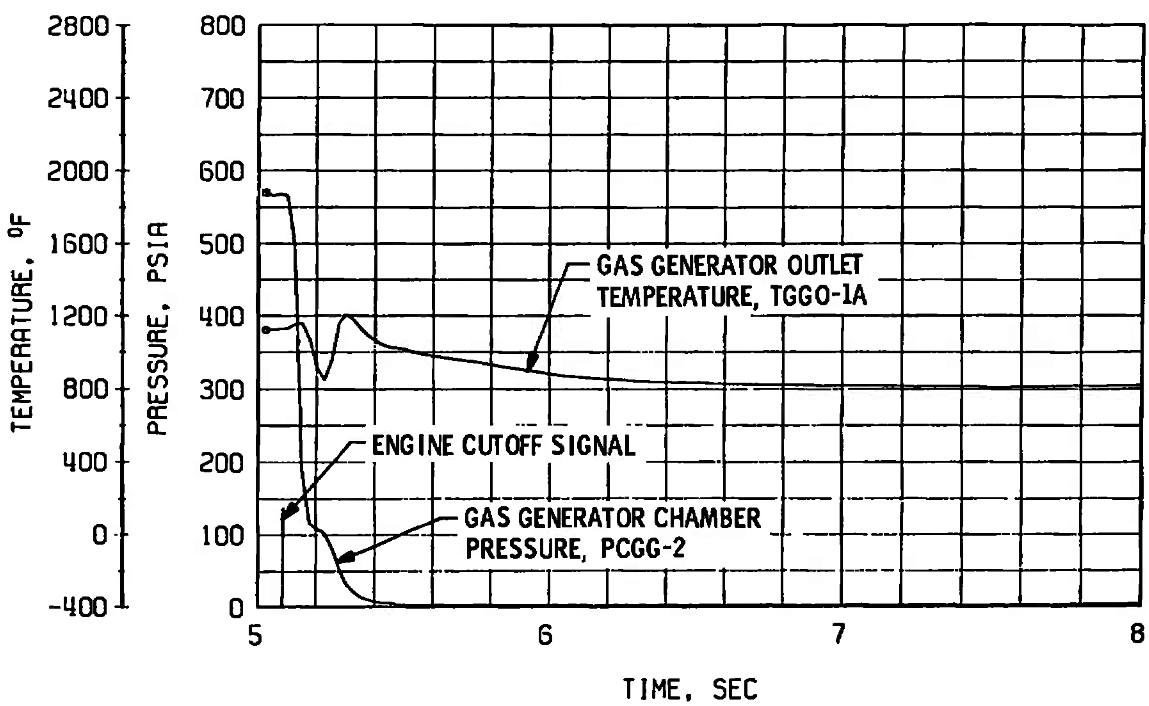


b. Thrust Chamber Oxidizer System, Shutdown

Fig. 17 Engine Shutdown Transient Operation, Firing 13B



c. Gas Generator Injector Pressures, Shutdown



d. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 17 Concluded

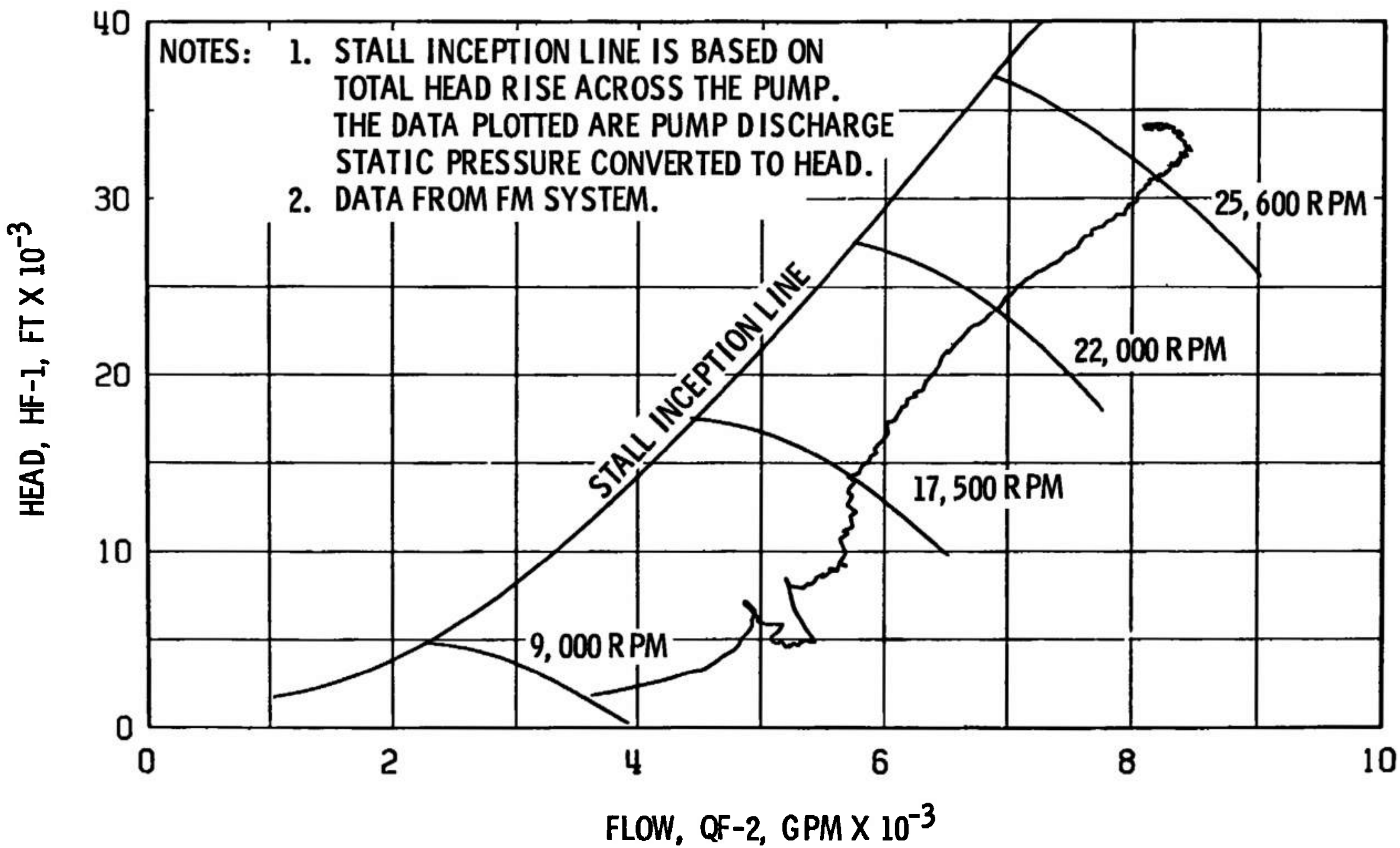
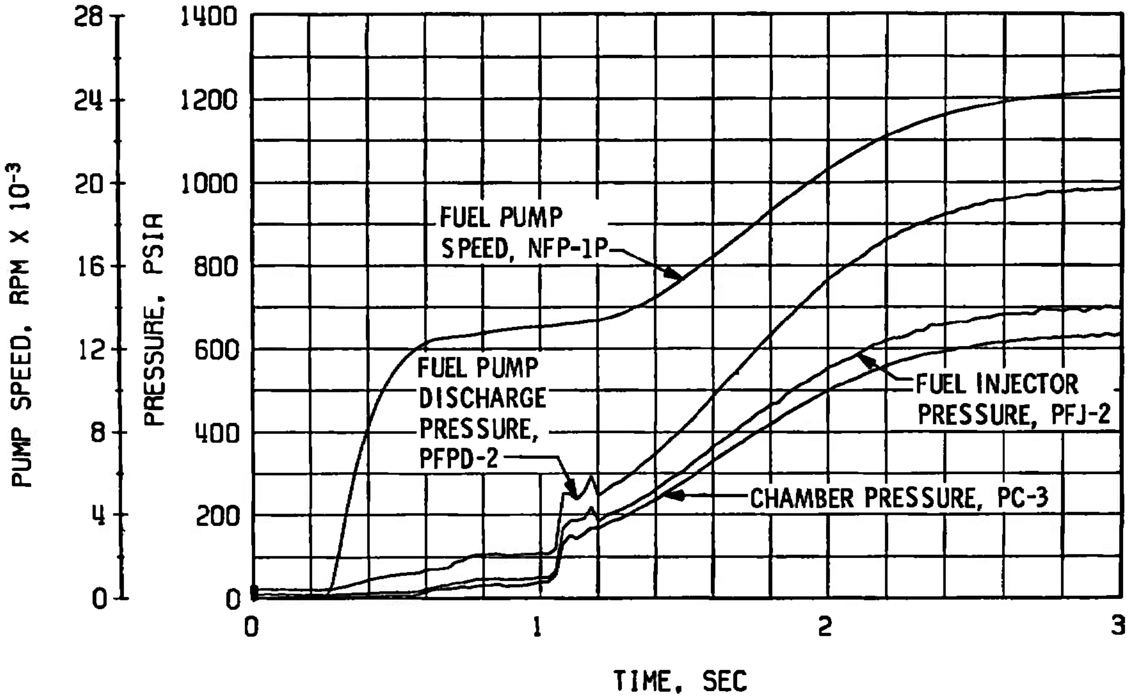
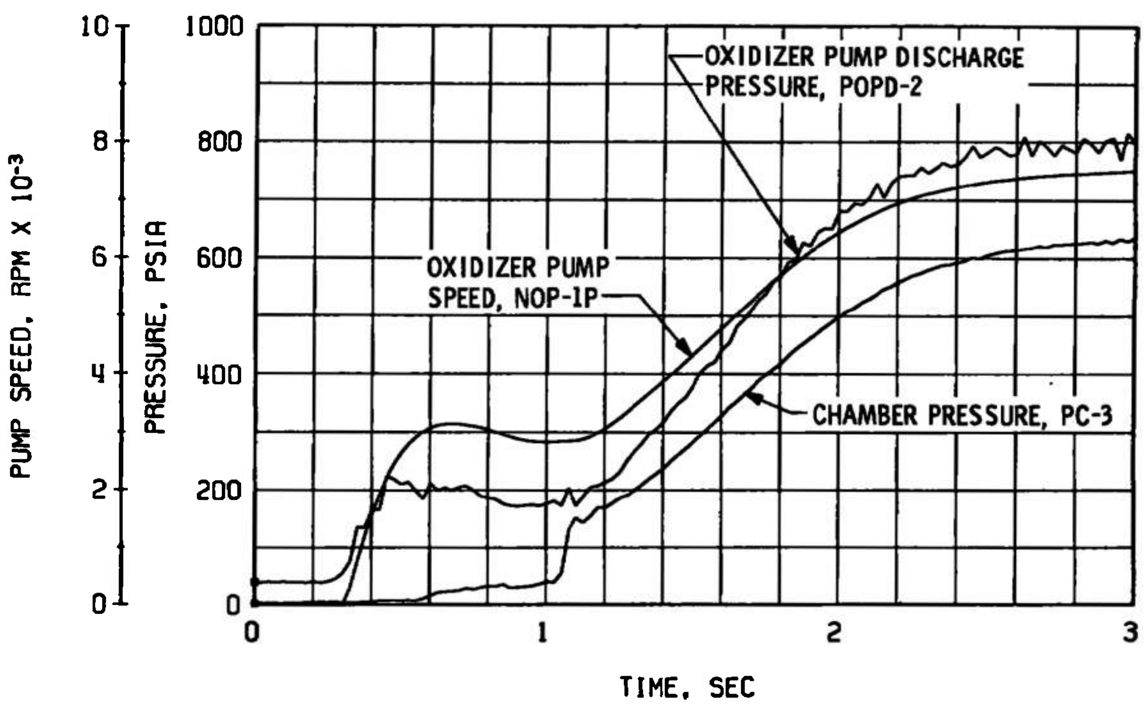


Fig. 18 Fuel Pump Start Transient Performance, Firing 13B

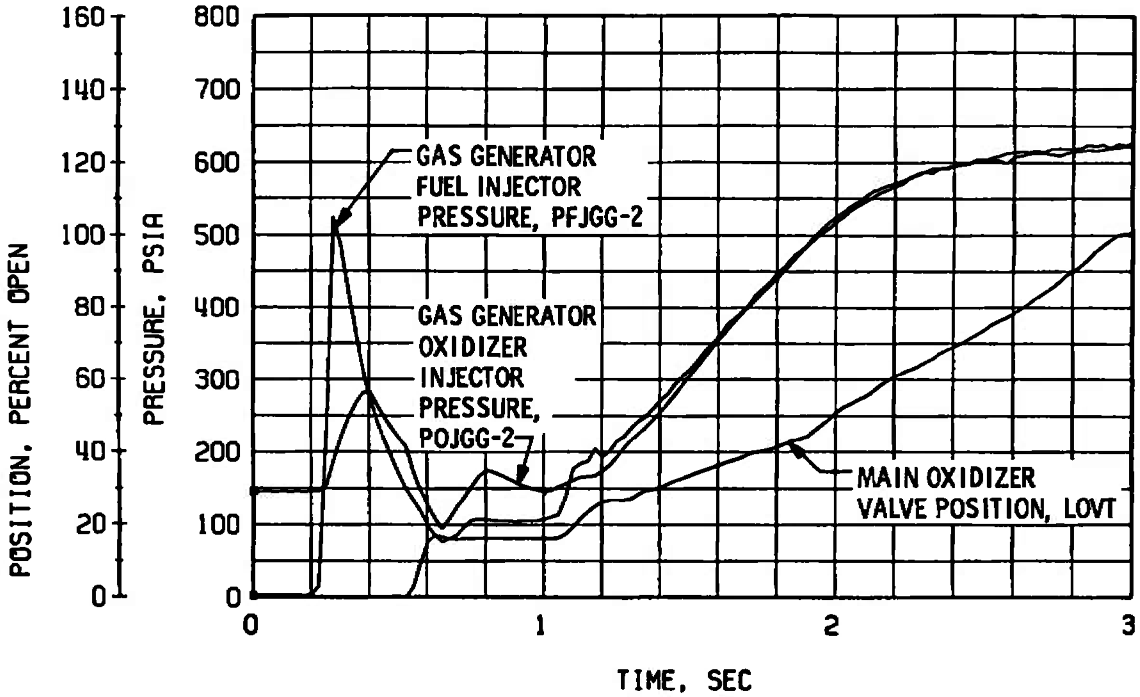


a. Thrust Chamber Fuel System, Start

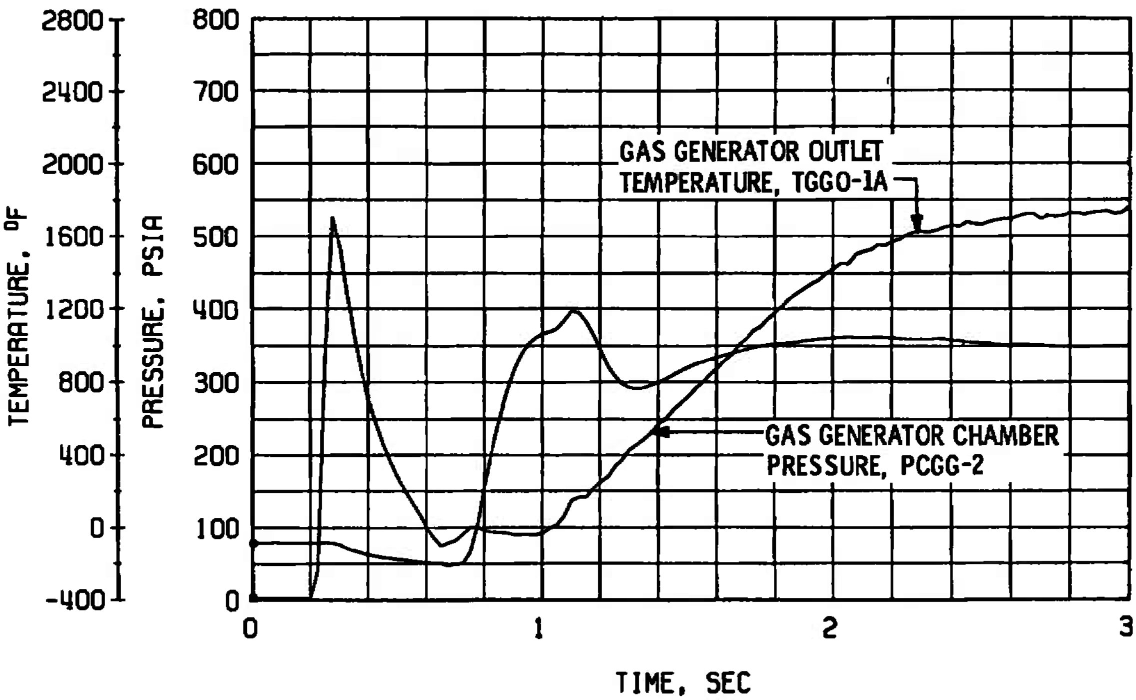


b. Thrust Chamber Oxidizer System, Start

Fig. 19 Engine Start Transient Operation, Firing 14A

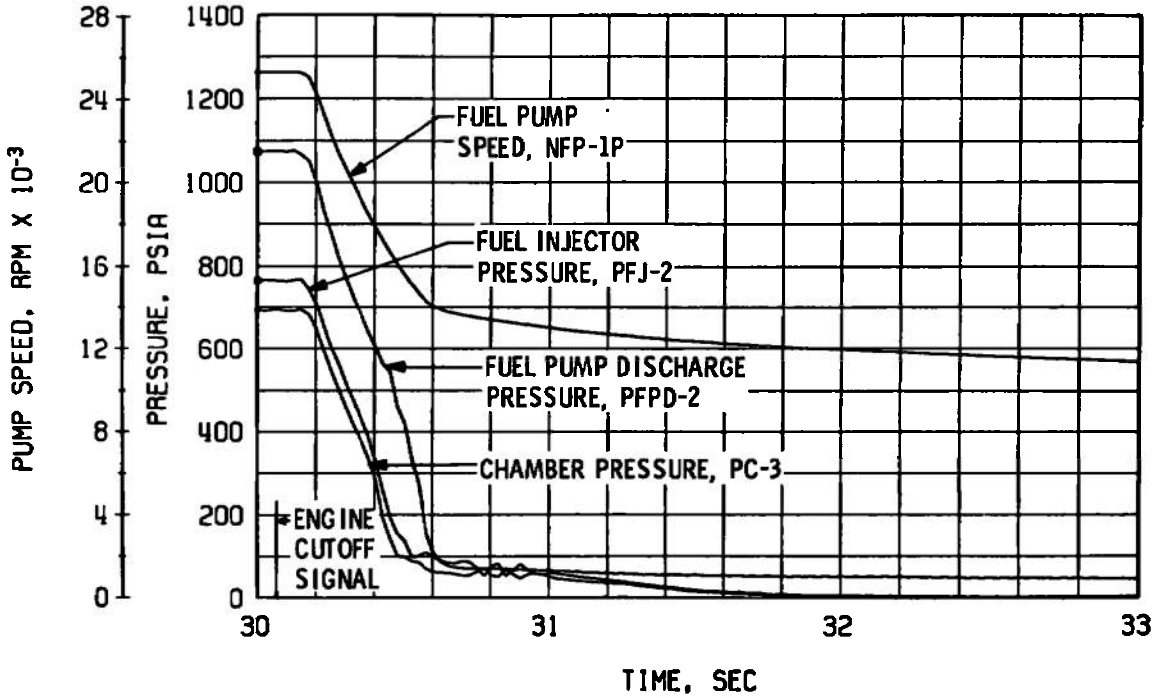


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

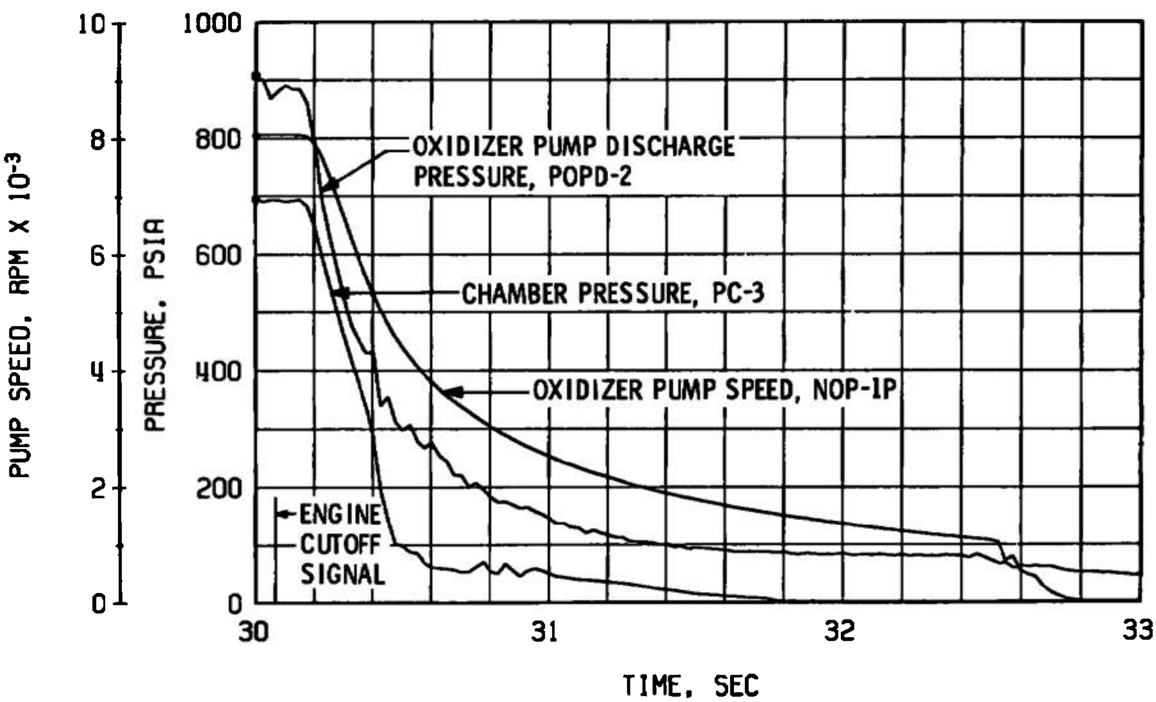


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 19 Concluded

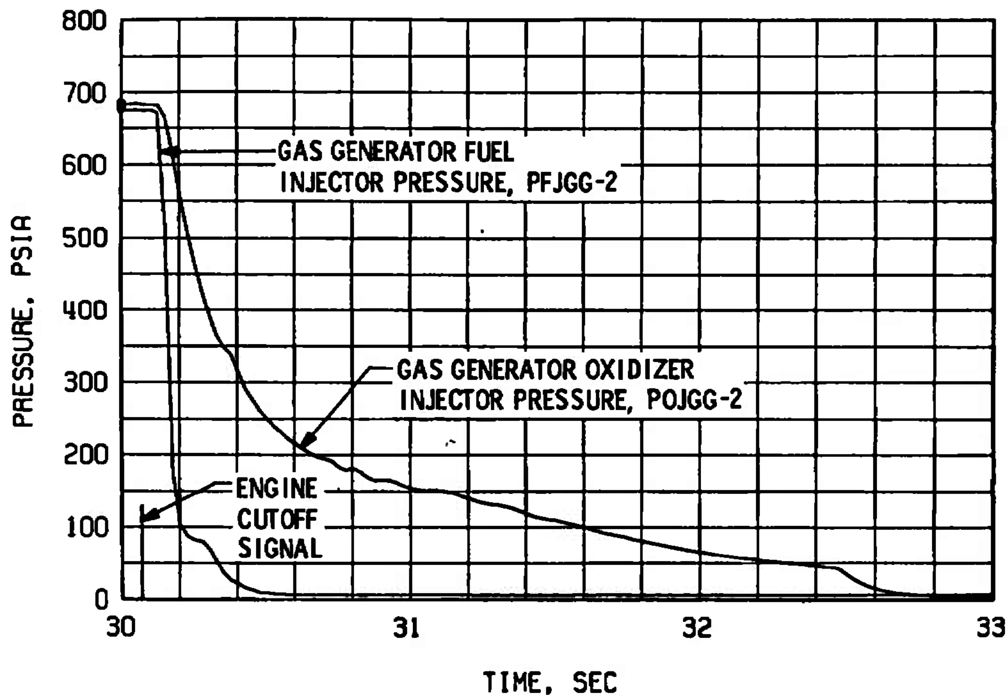


a. Thrust Chamber Fuel System, Shutdown

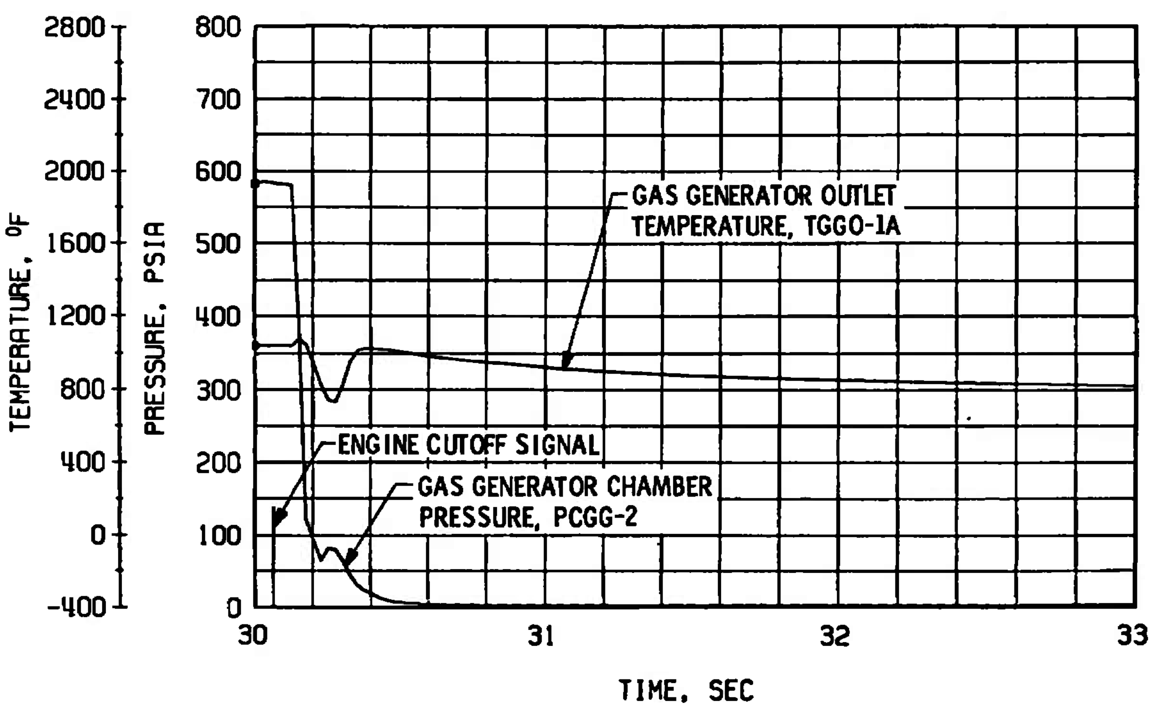


b. Thrust Chamber Oxidizer System, Shutdown

Fig. 20 Engine Shutdown Transient Operation, Firing 14A



c. Gas Generator Injector Pressures, Shutdown



d. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 20 Concluded

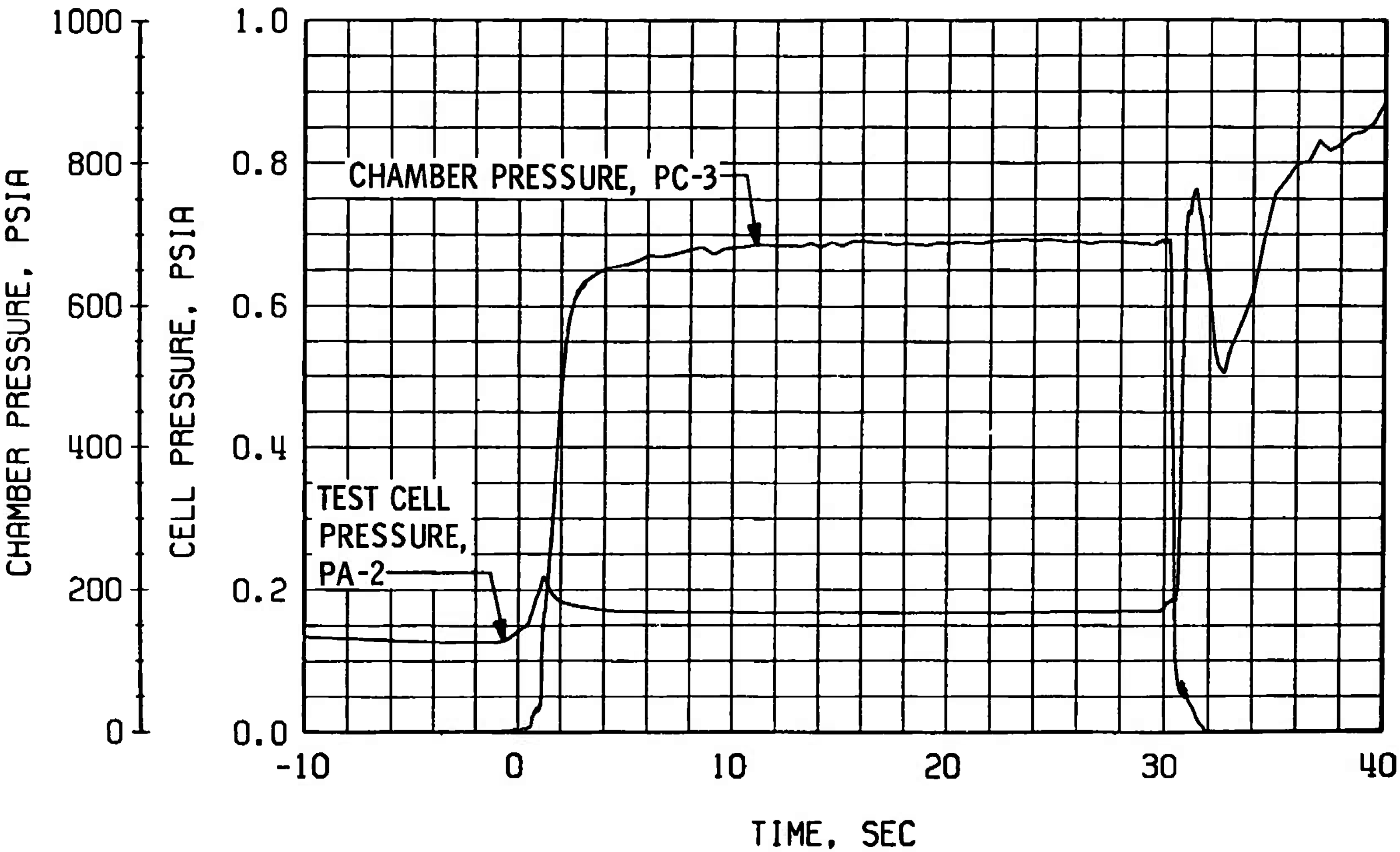
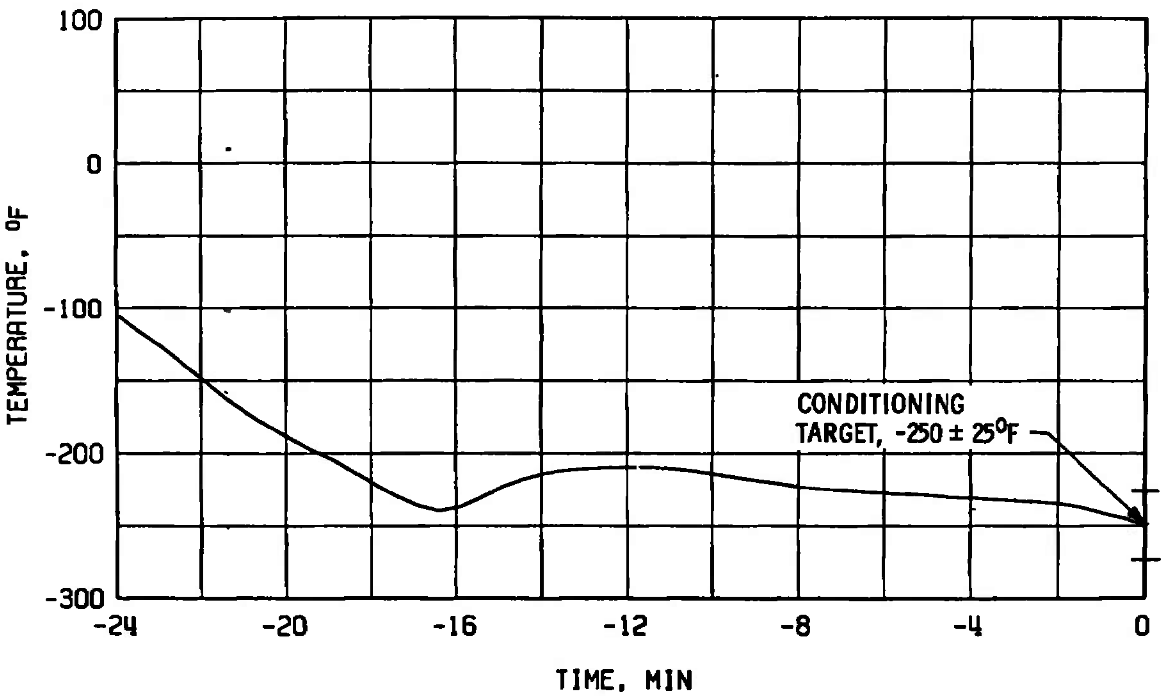
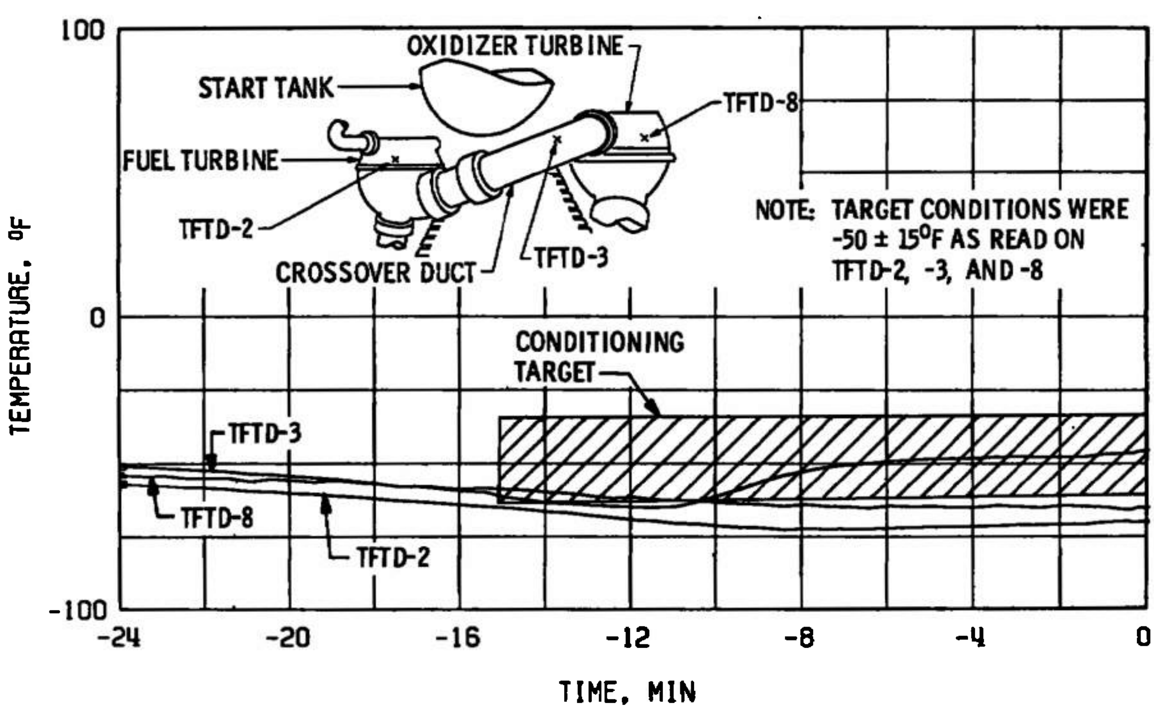


Fig. 21 Engine Ambient and Combustion Chamber Pressures, Firing 14A

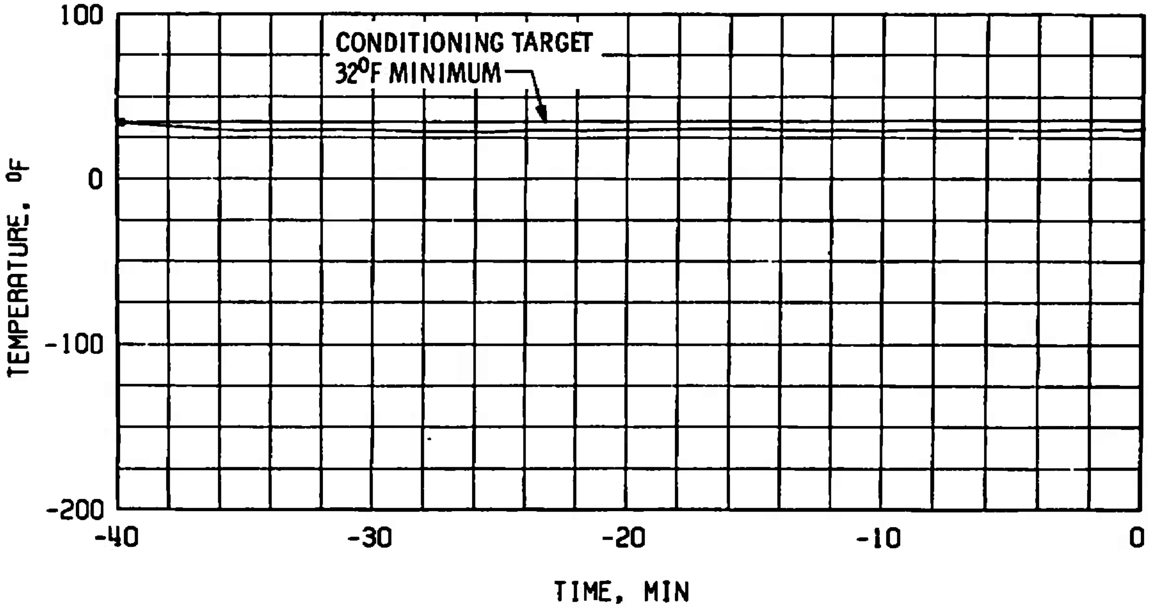


a. Thrust Chamber Throat, TTC-1P

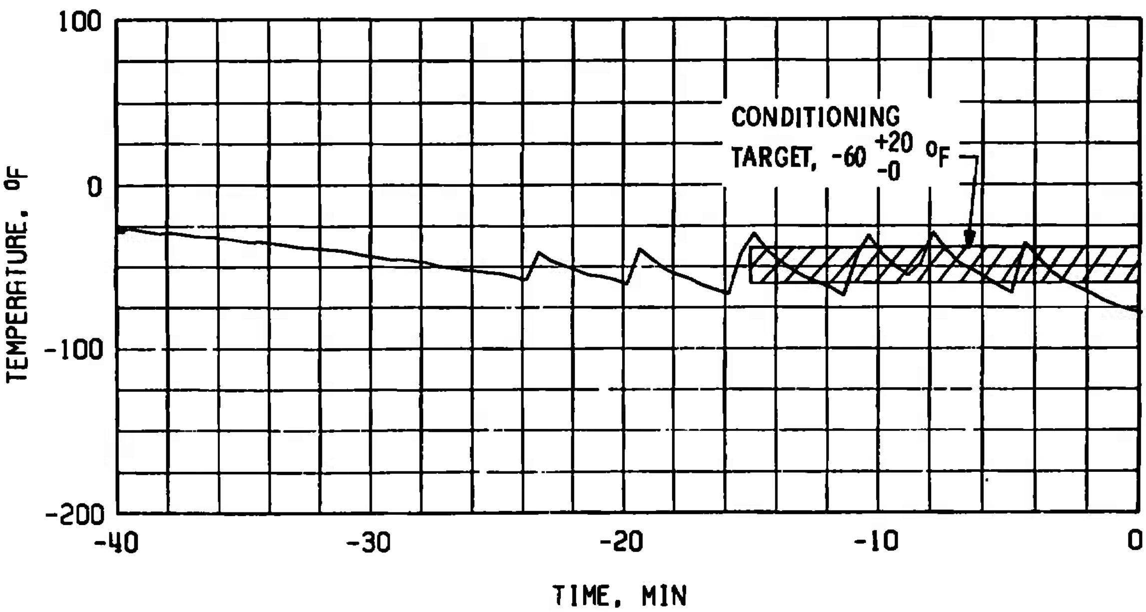


b. Crossover Duct, TFTD

Fig. 22 Thermal Conditioning History of Engine Components, Firing 14A



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 22 Concluded

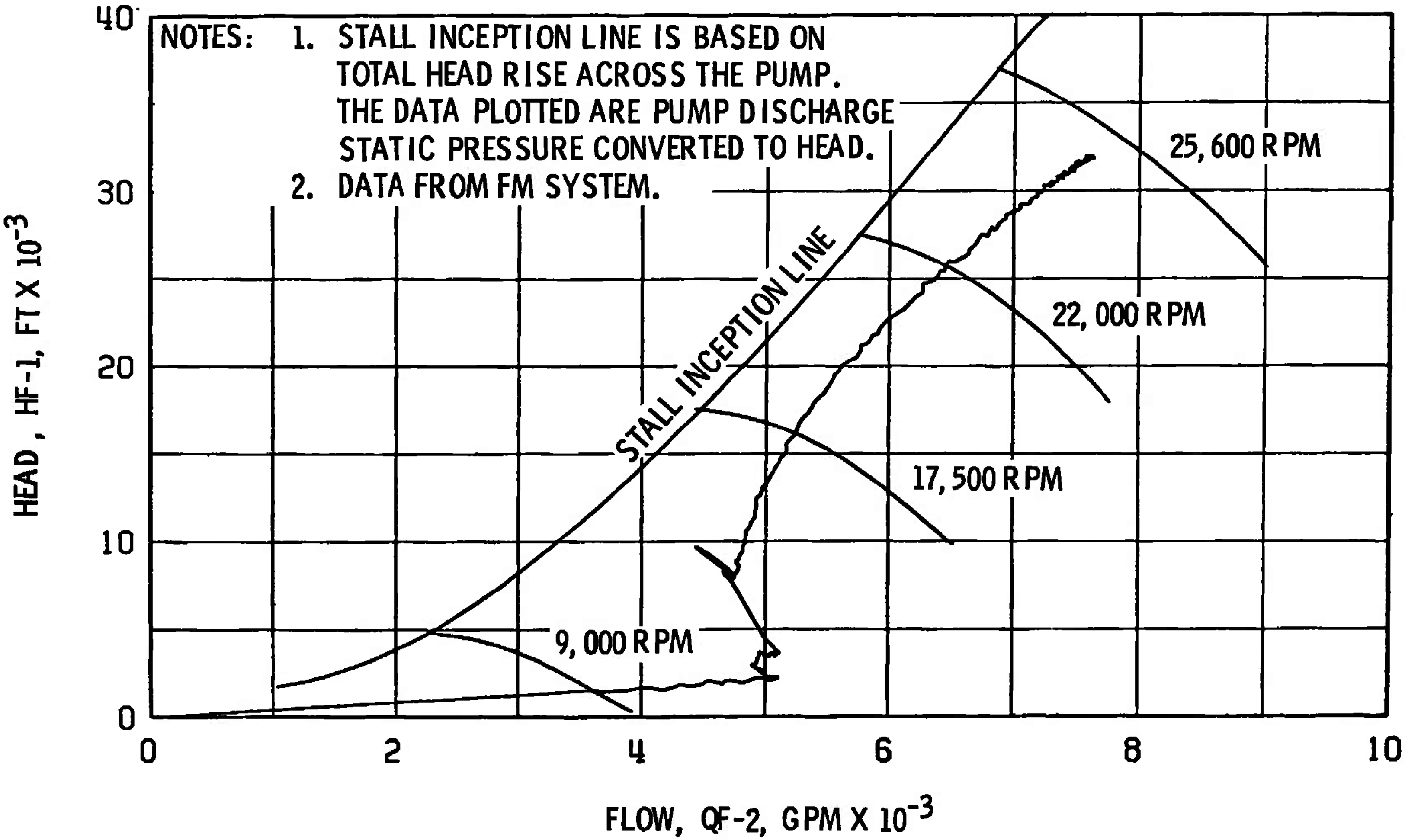
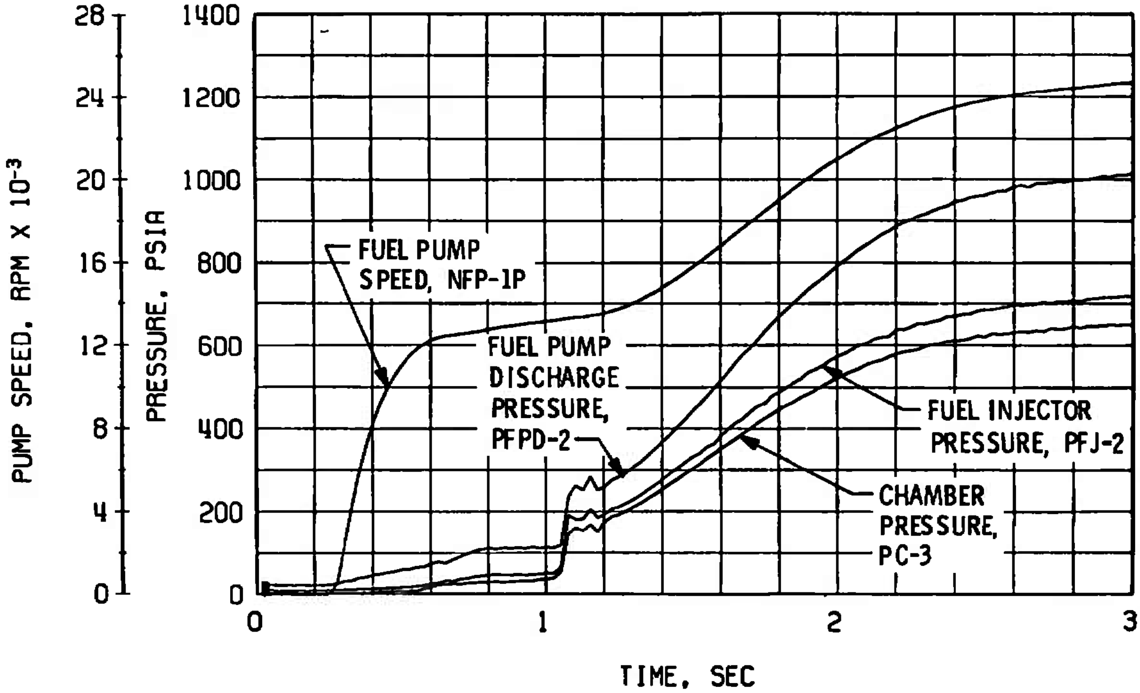
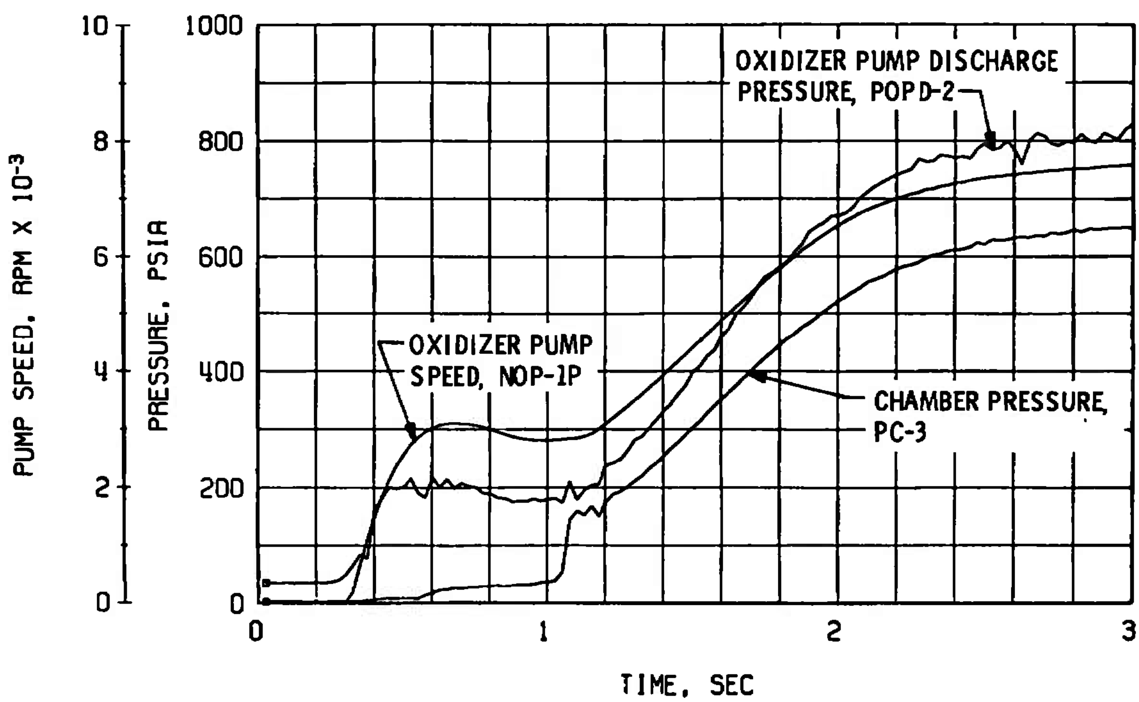


Fig. 23 Fuel Pump Start Transient Performance, Firing 14A

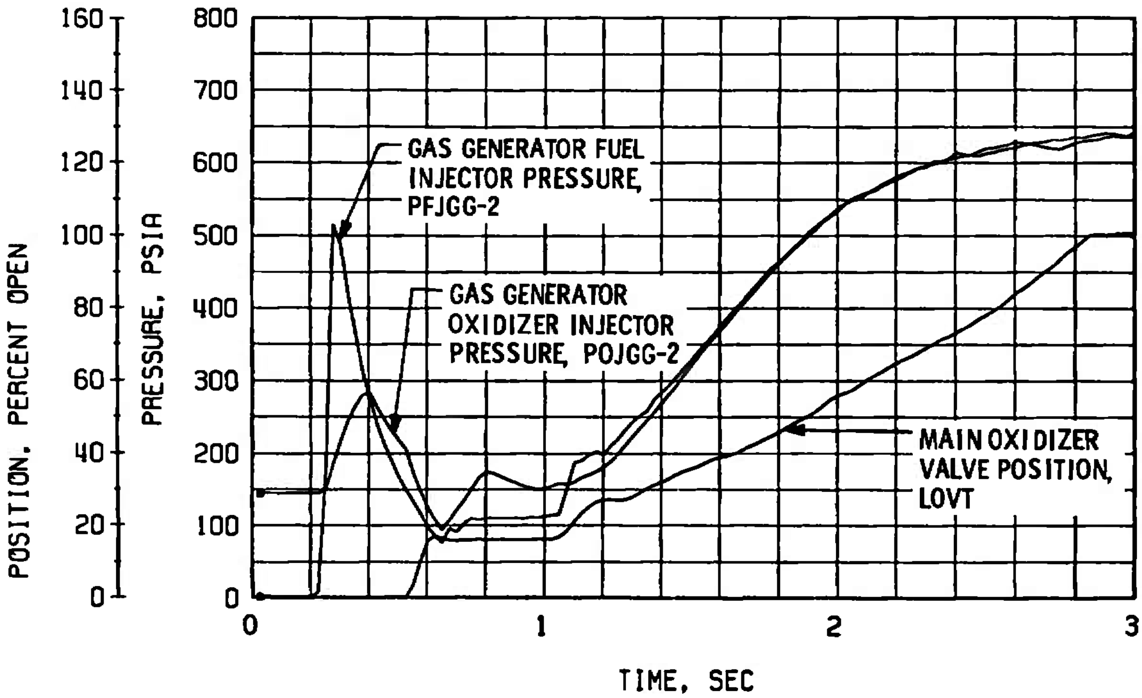


a. Thrust Chamber Fuel System, Start

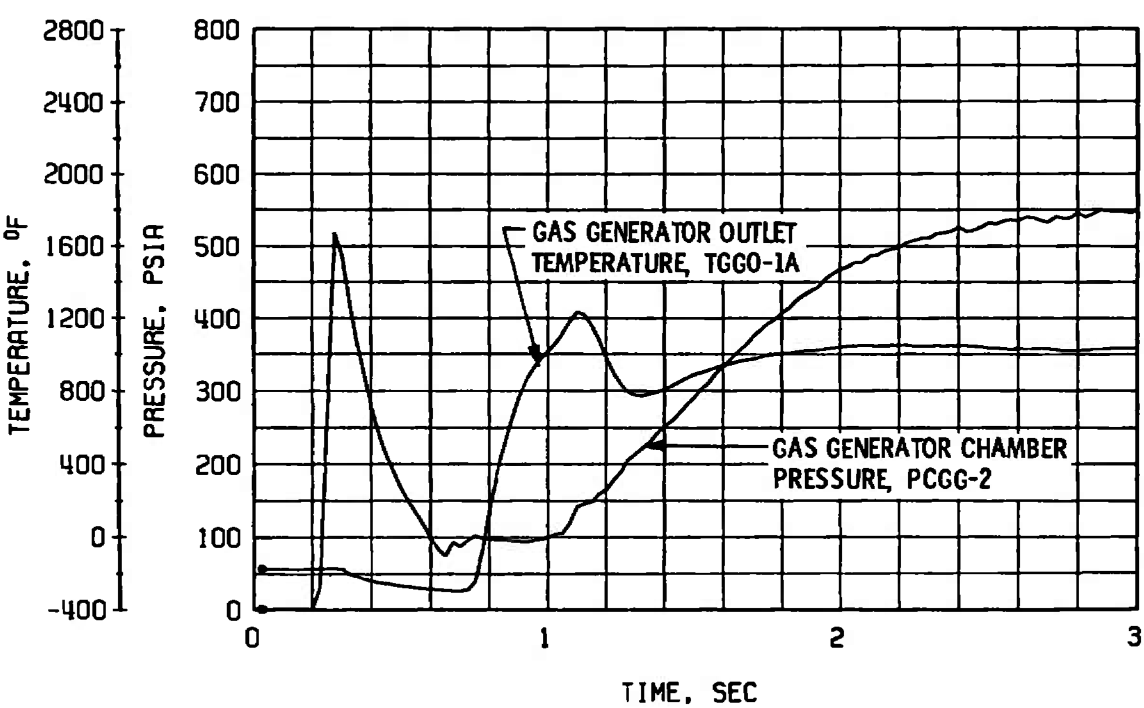


b. Thrust Chamber Oxidizer System, Start

Fig. 24 Engine Start Transient Operation, Firing 15A

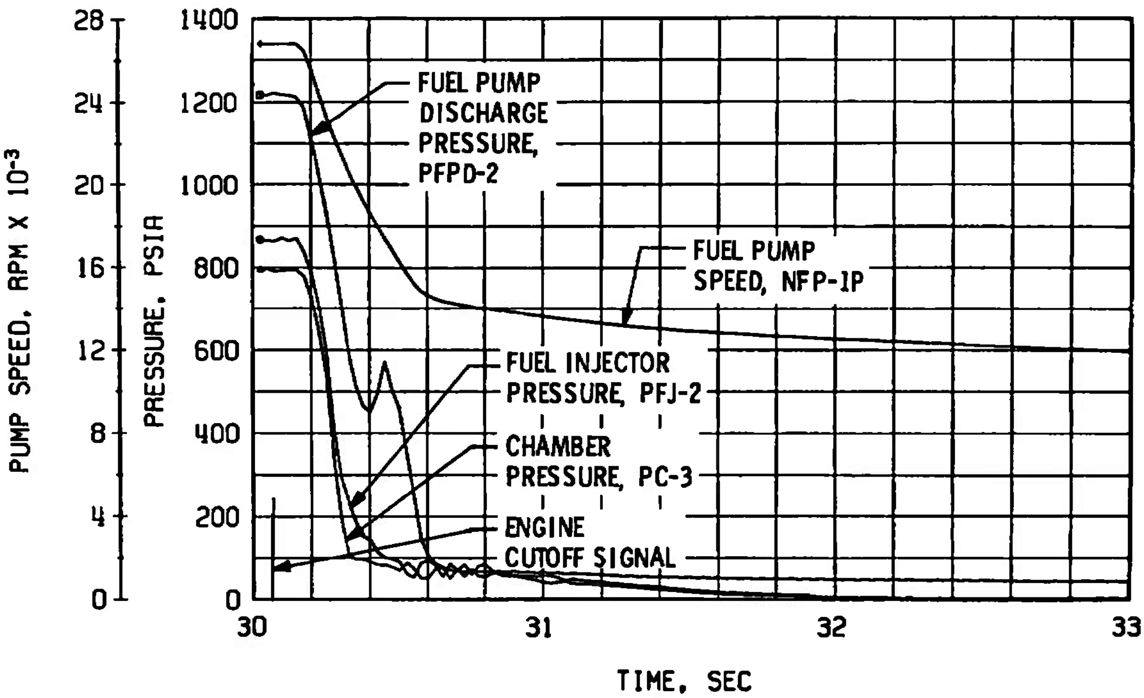


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

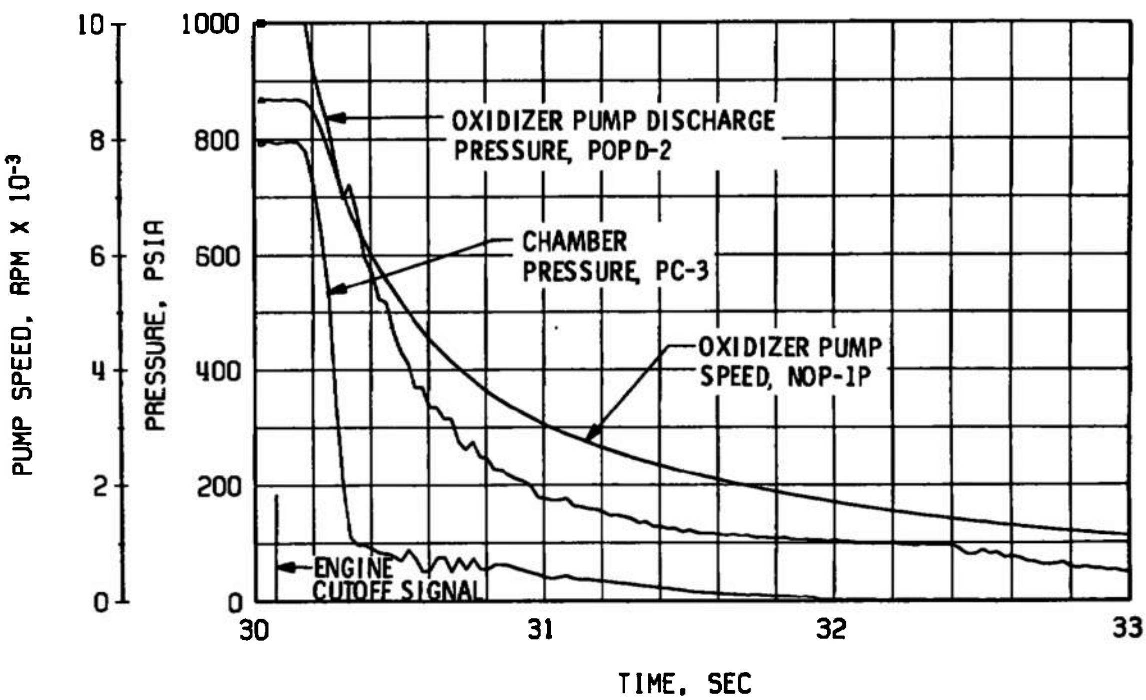


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 24 Concluded

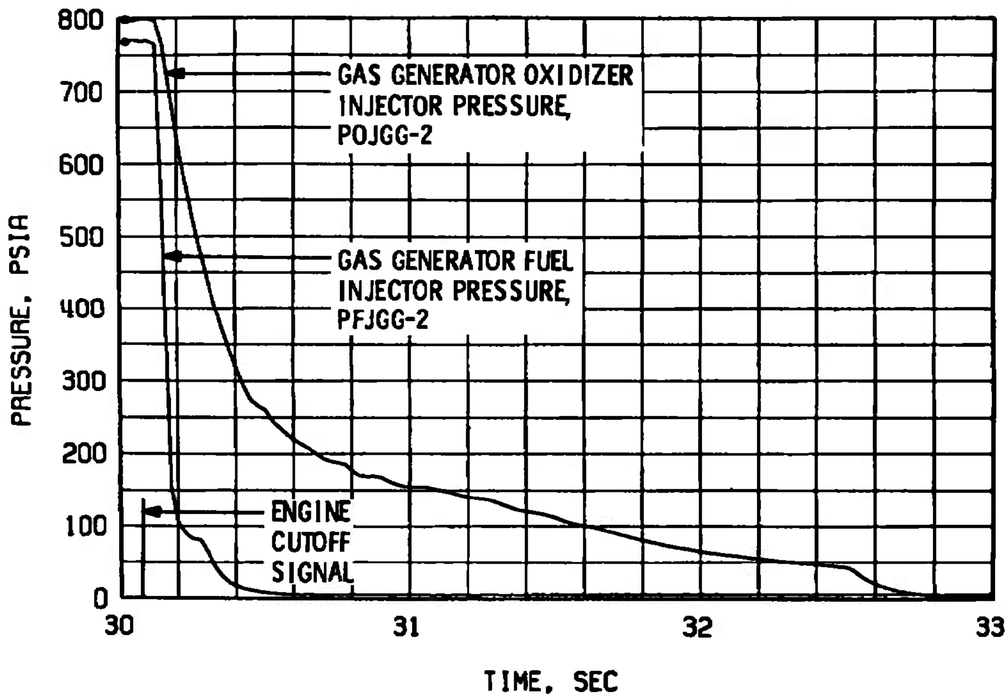


a. Thrust Chamber Fuel System, Shutdown

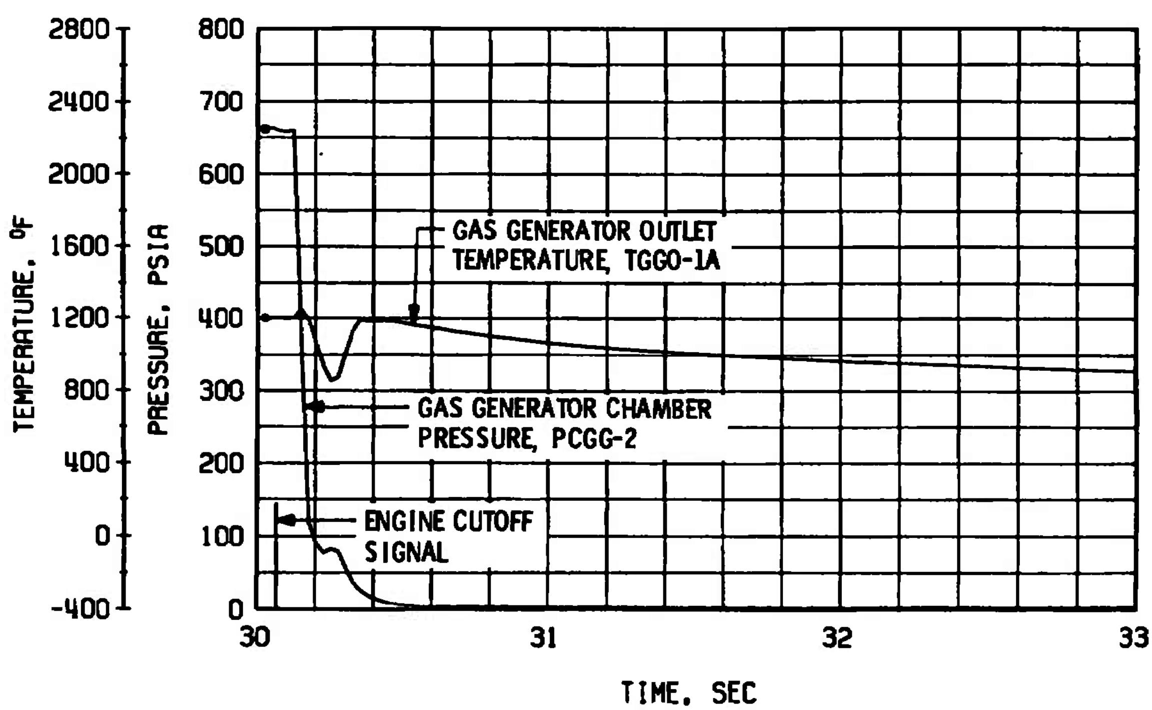


b. Thrust Chamber Oxidizer System, Shutdown

Fig. 25 Engine Shutdown Transient Operation, Firing 15A



c. Gas Generator Injector Pressures, Shutdown



d. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 25 Concluded

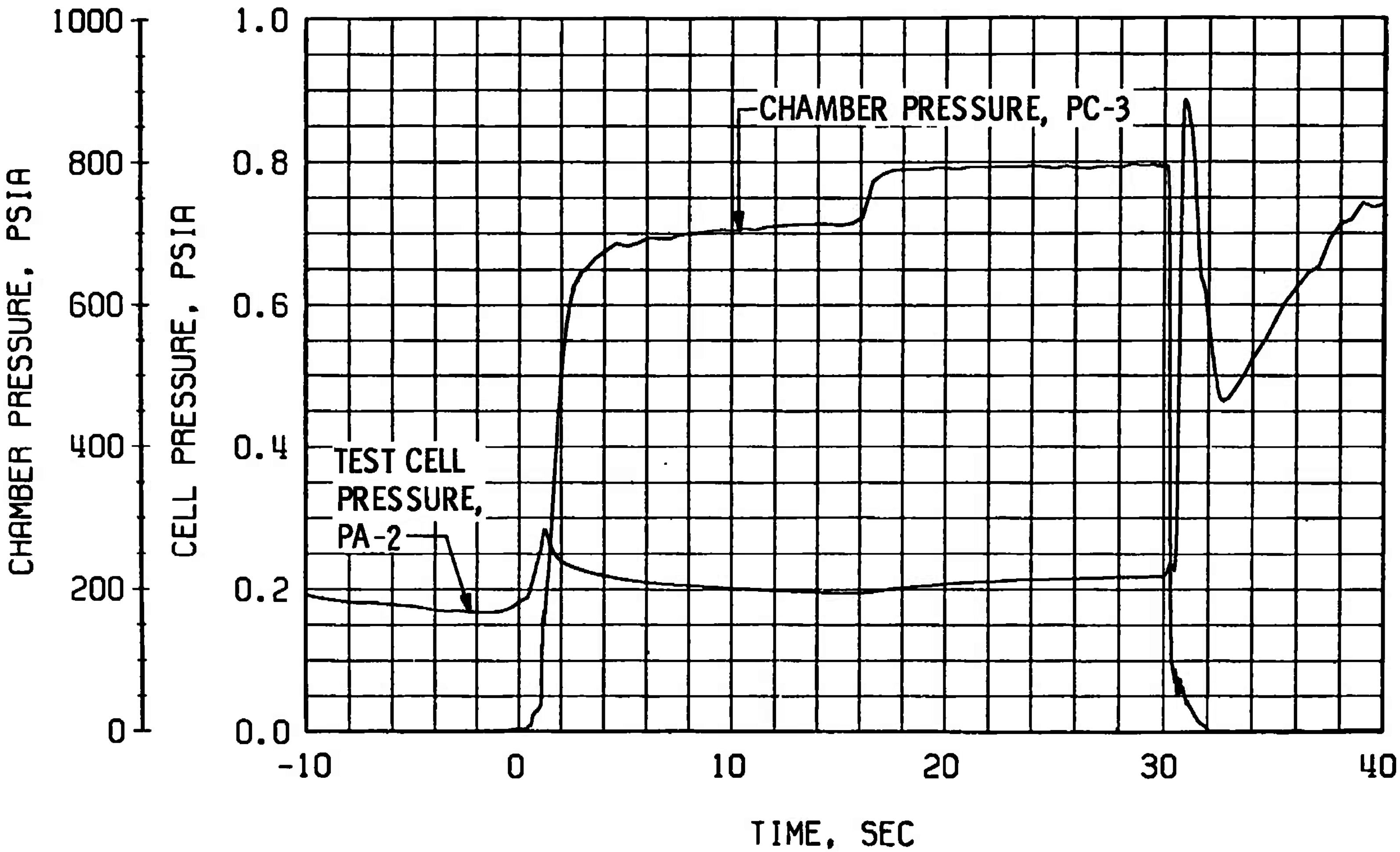
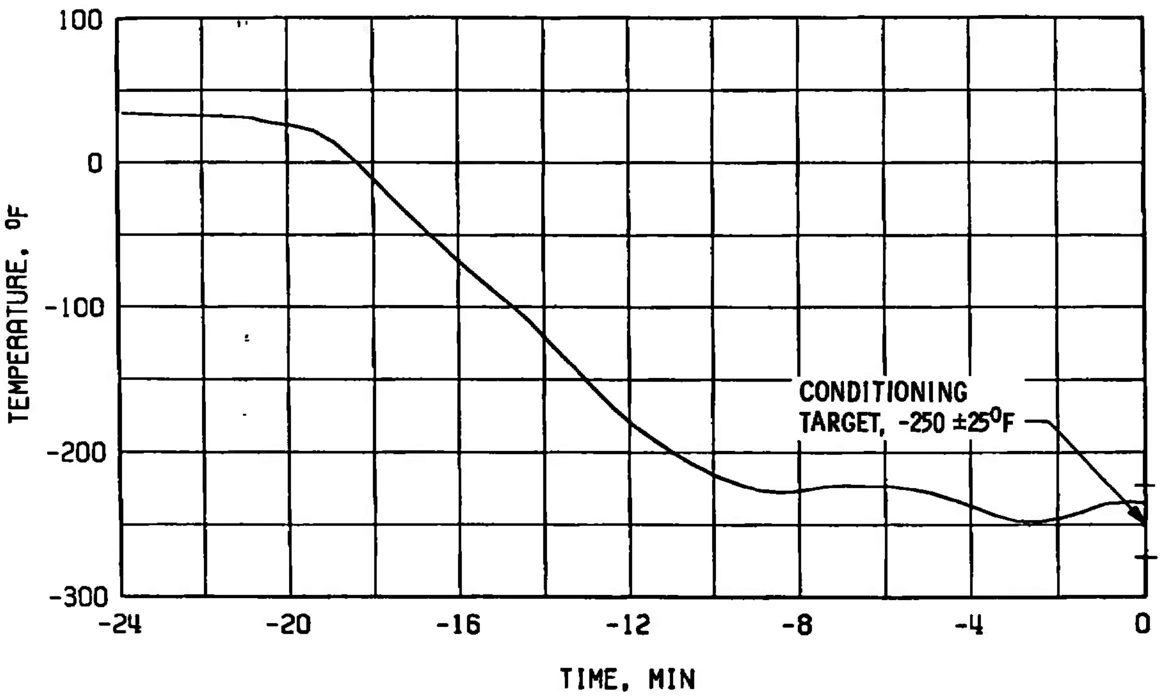
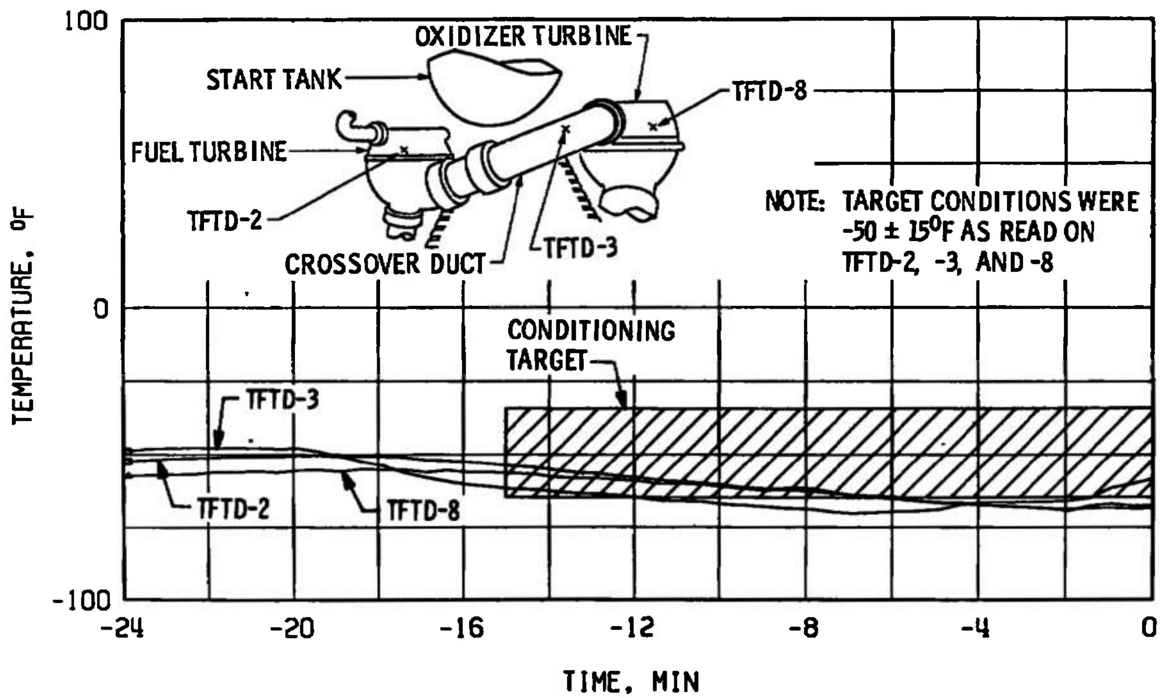


Fig. 26 Engine Ambient and Combustion Chamber Pressures, Firing 15A

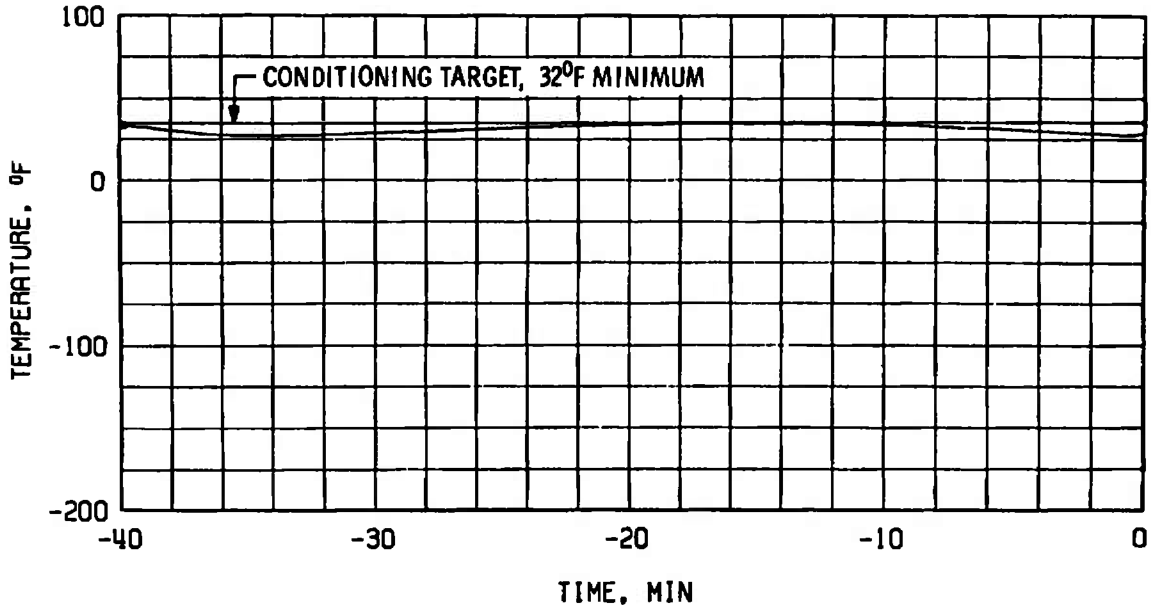


a. Thrust Chamber Throat, TTC-1P

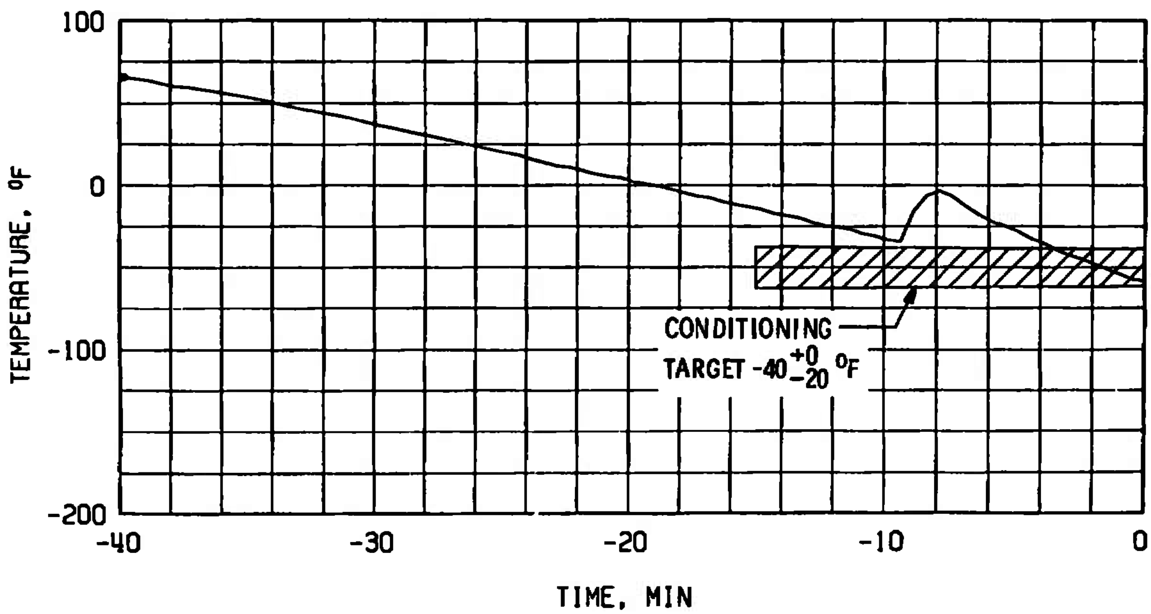


b. Crossover Duct, TFTD

Fig. 27 Thermal Conditioning History of Engine Components, Firing 15A



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 27 Concluded

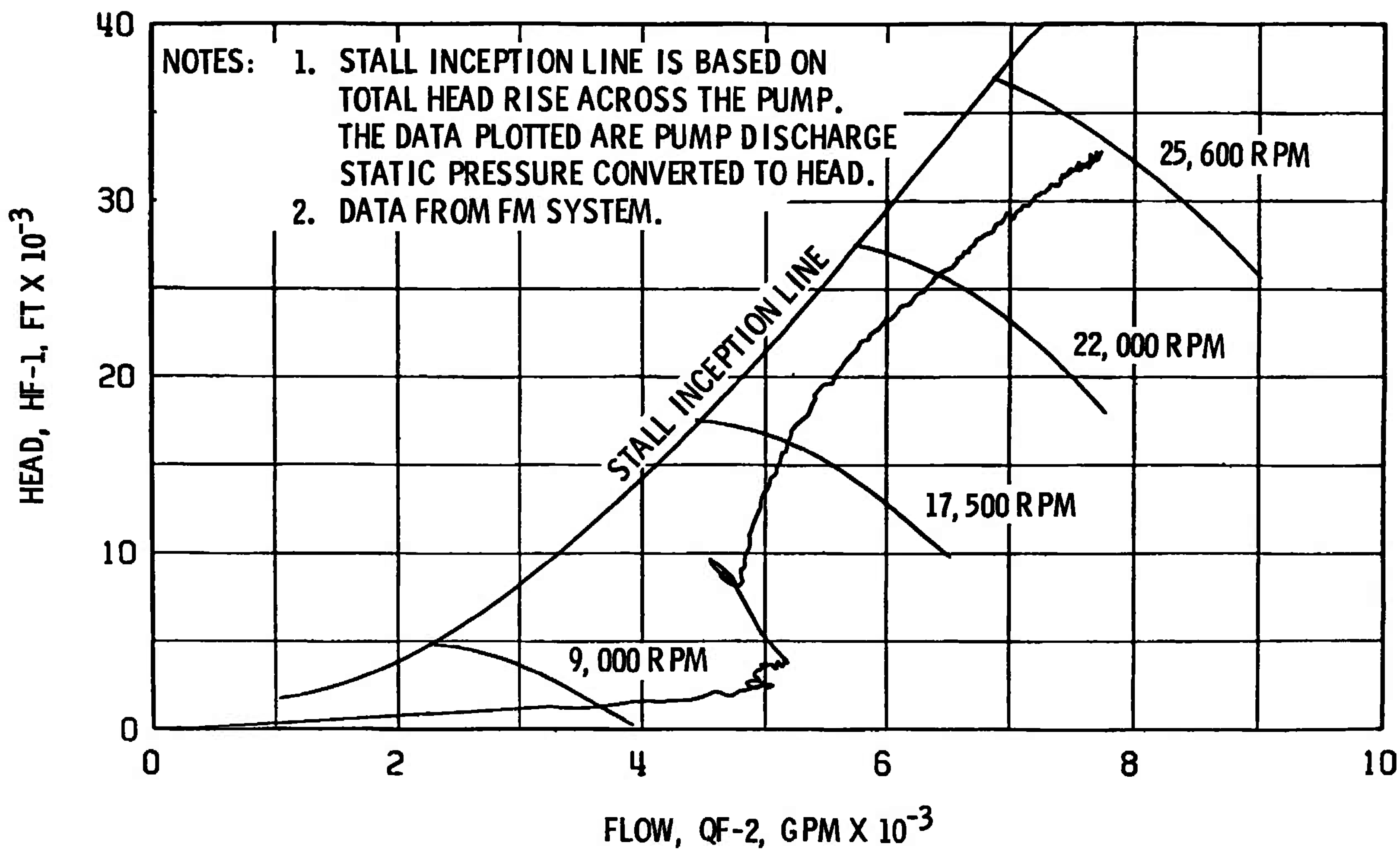
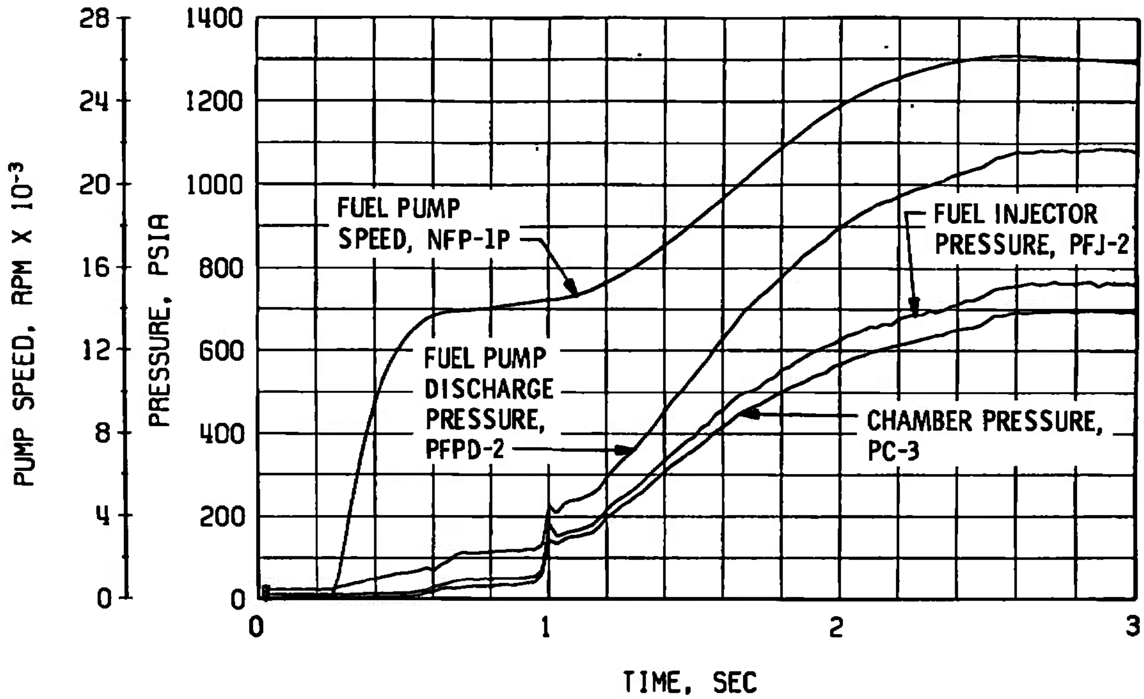
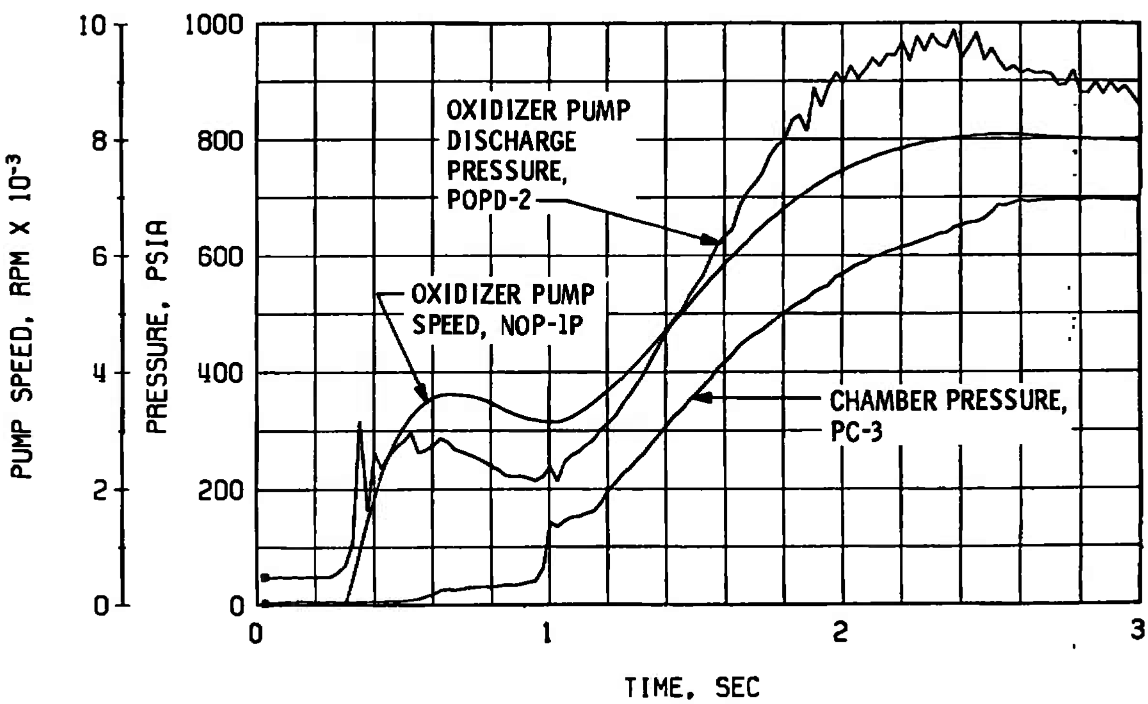


Fig. 28 Fuel Pump Start Transient Performance, Firing 15A

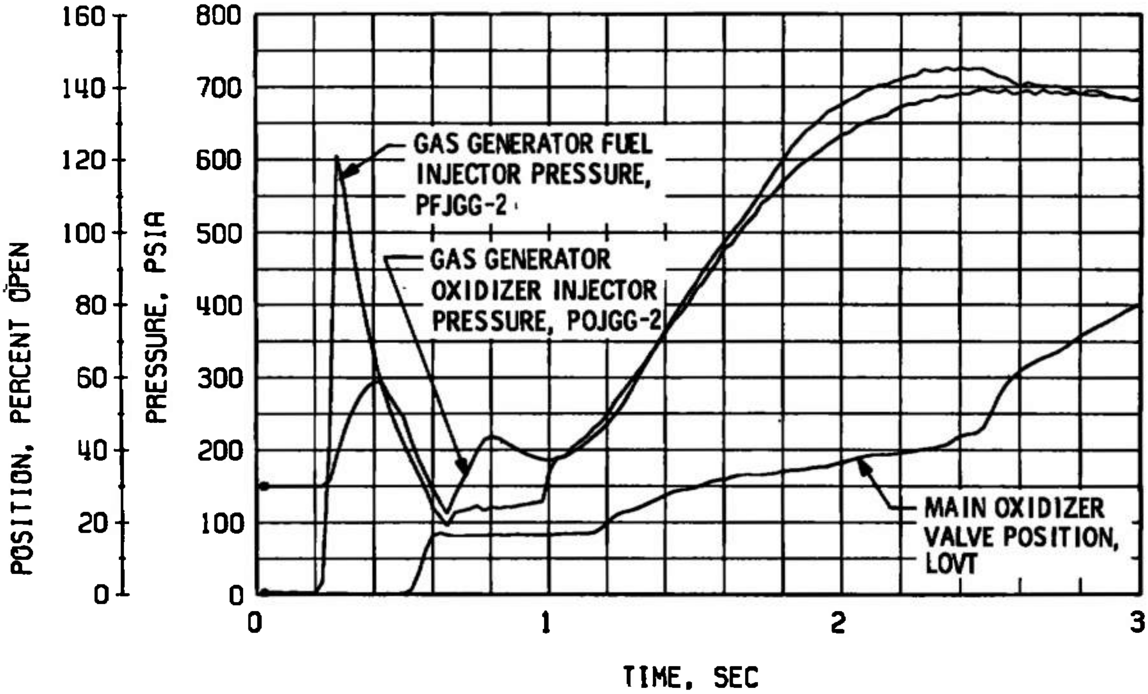


a. Thrust Chamber Fuel System, Start

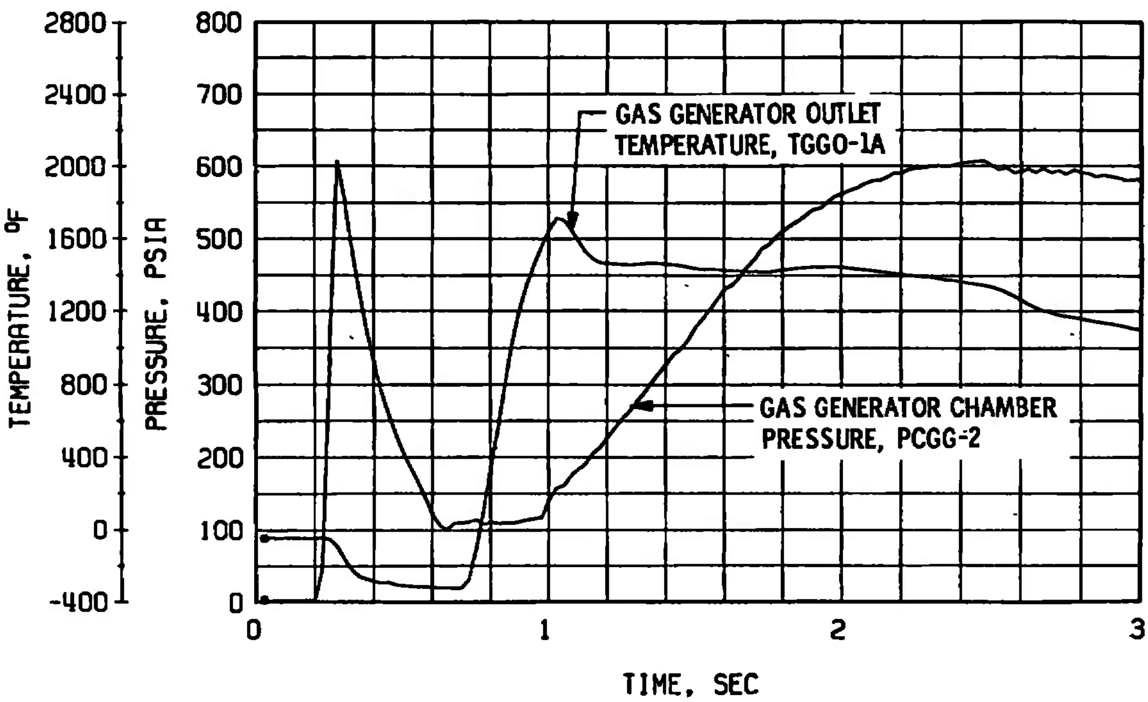


b. Thrust Chamber Oxidizer System, Start

Fig. 29 Engine Start Transient Operation, Firing 15B

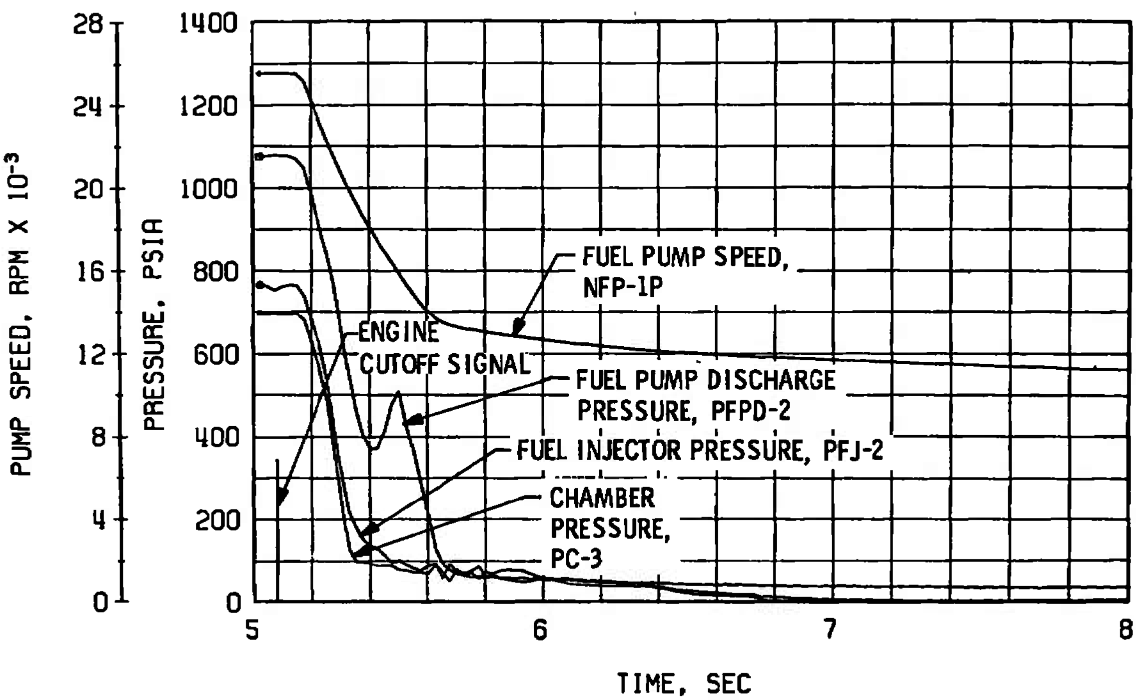


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

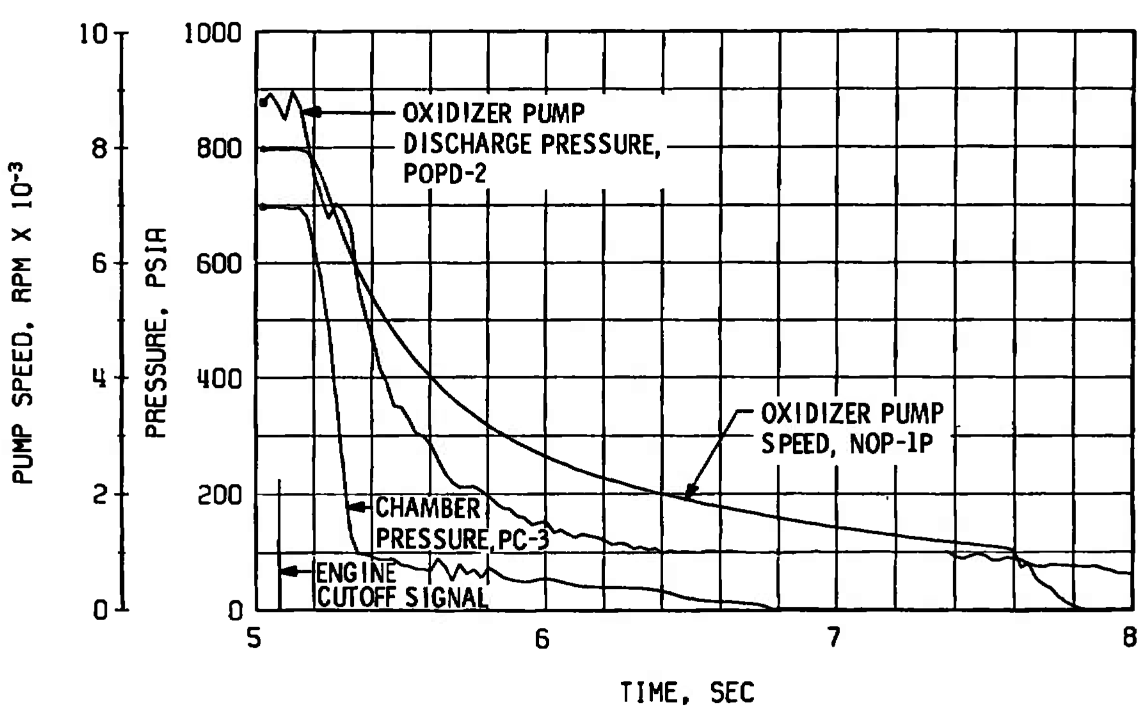


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 29 Concluded

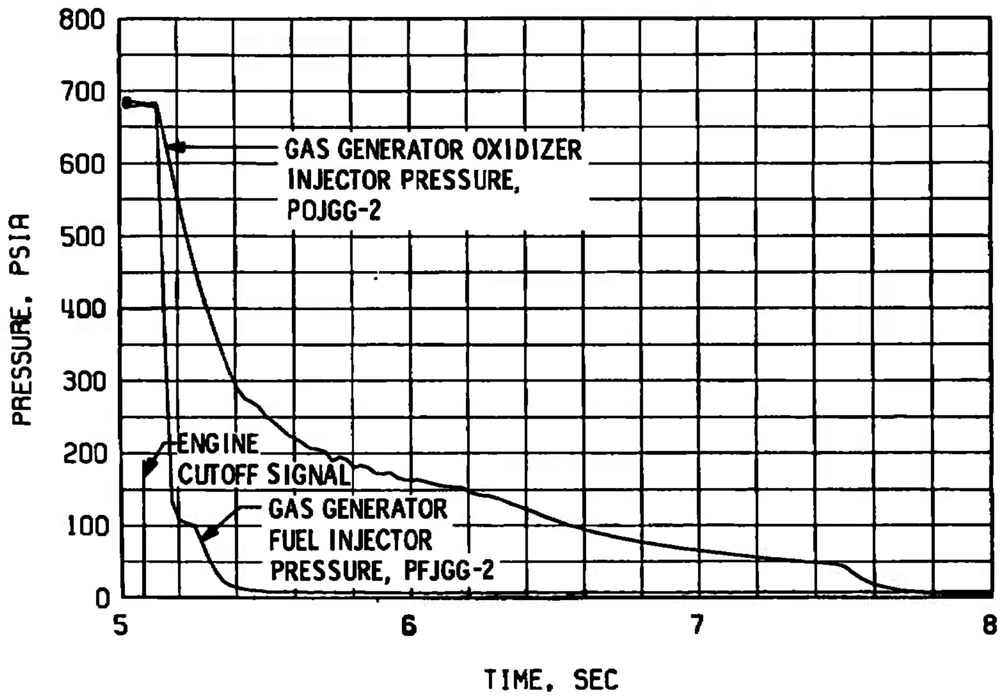


a. Thrust Chamber Fuel System, Shutdown

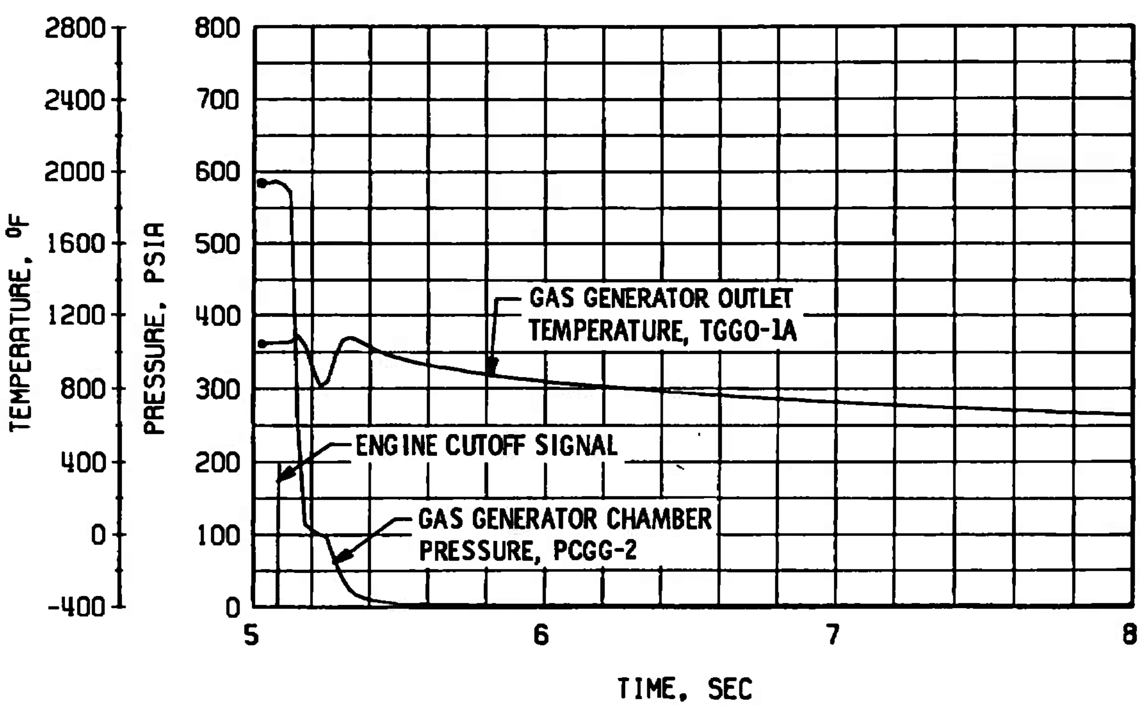


b. Thrust Chamber Oxidizer System, Shutdown

Fig. 30 Engine Shutdown Transient Operation, Firing 15B



c. Gas Generator Injector Pressures, Shutdown



d. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 30 Concluded

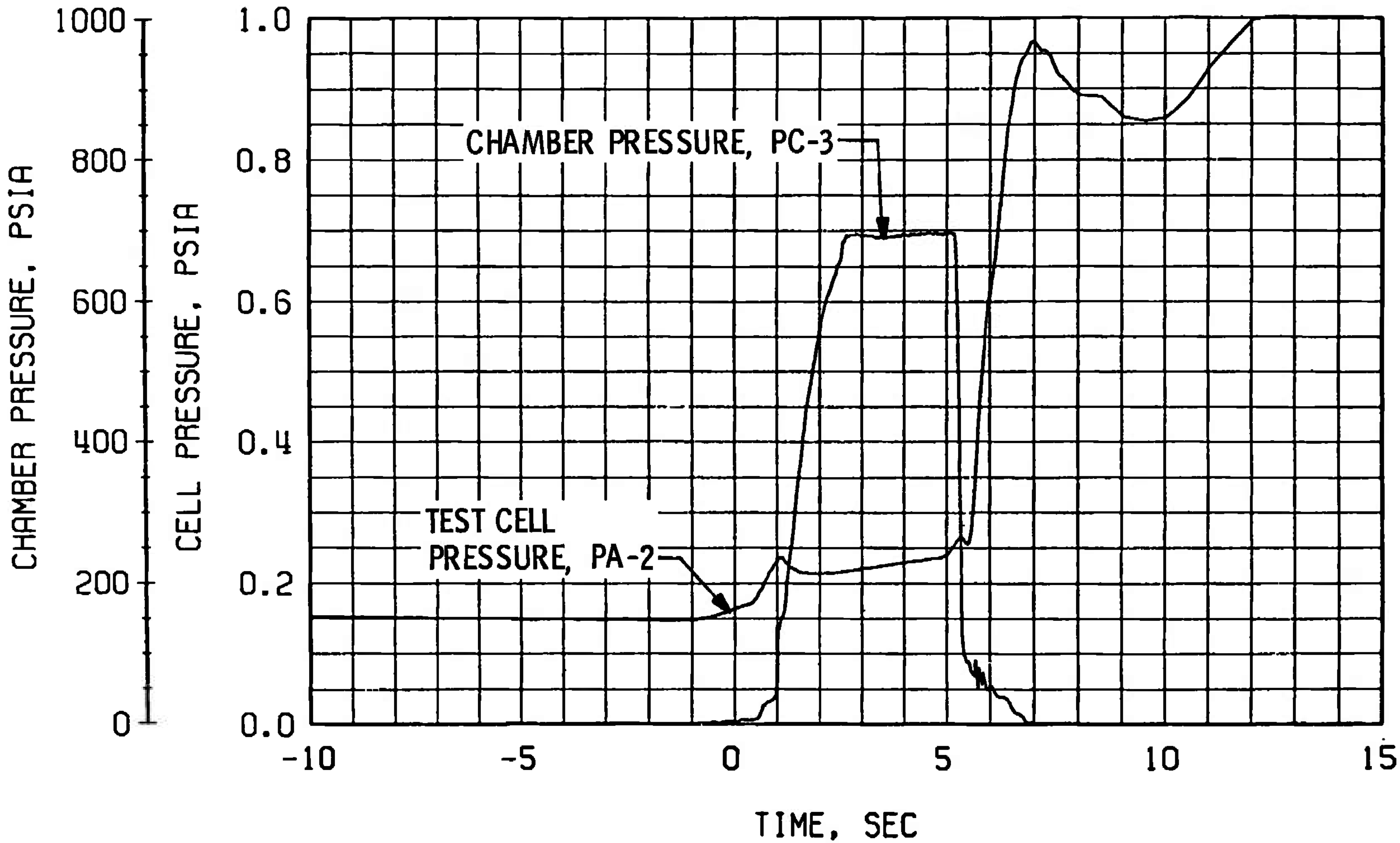
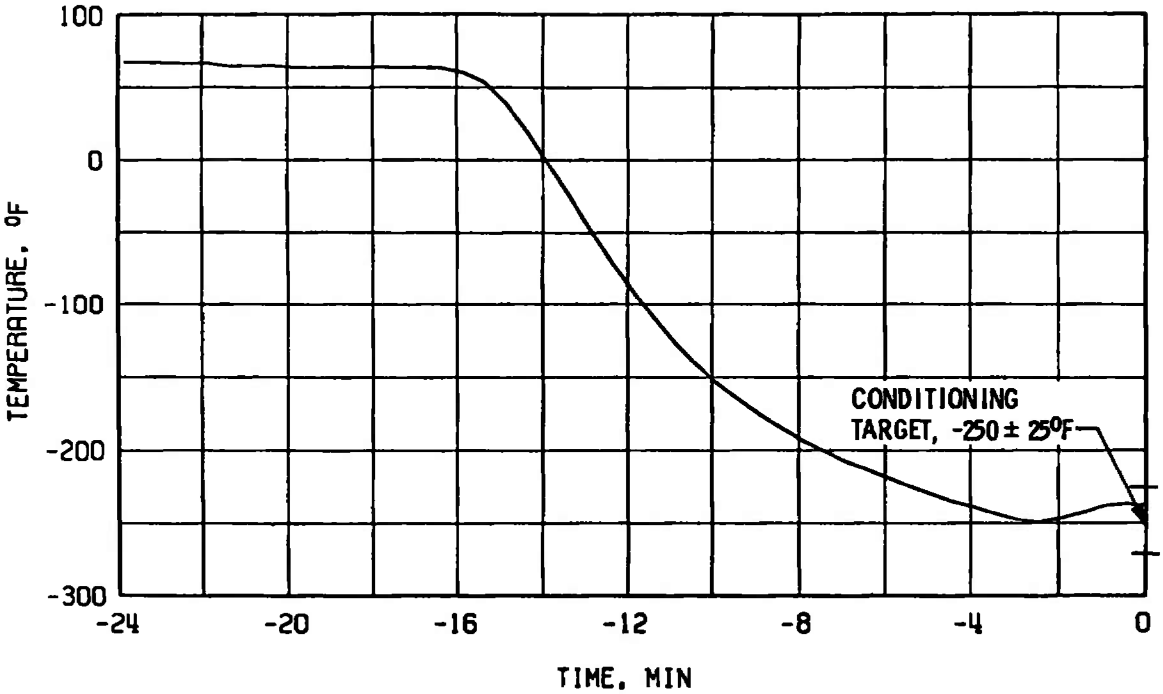
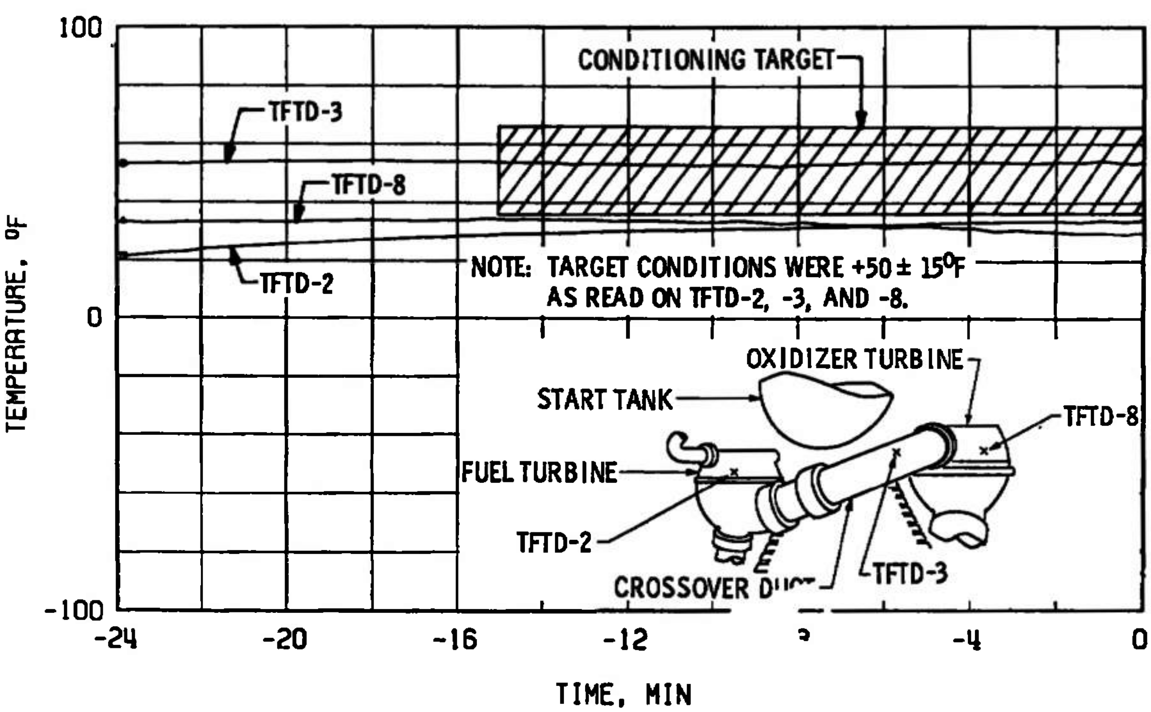


Fig. 31 Engine Ambient and Combustion Chamber Pressures, Firing 15B

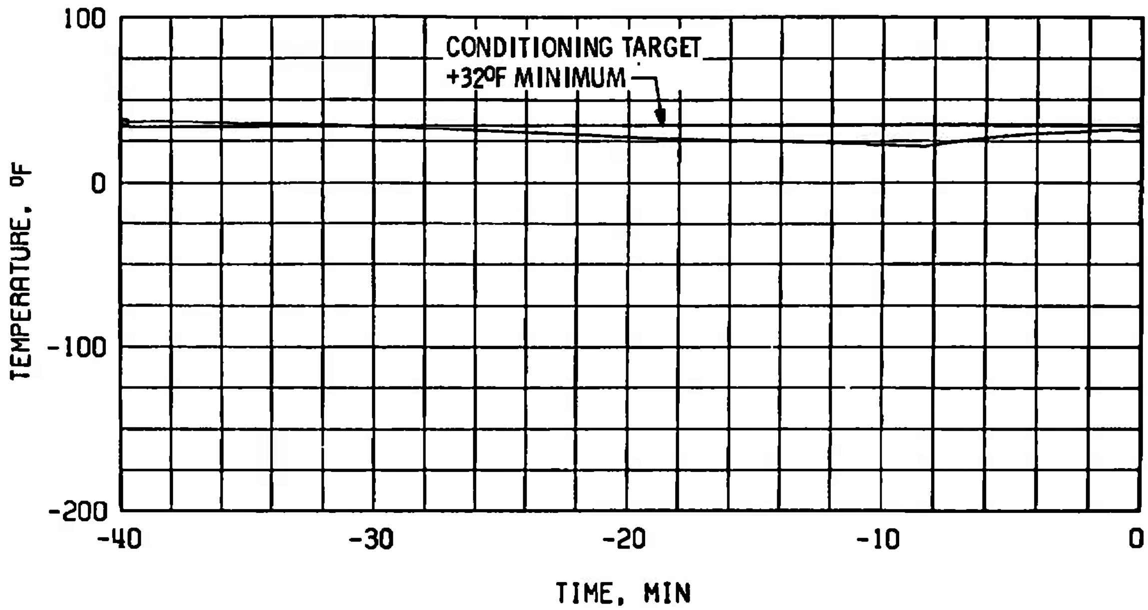


a. Thrust Chamber Throat, TTC-1P

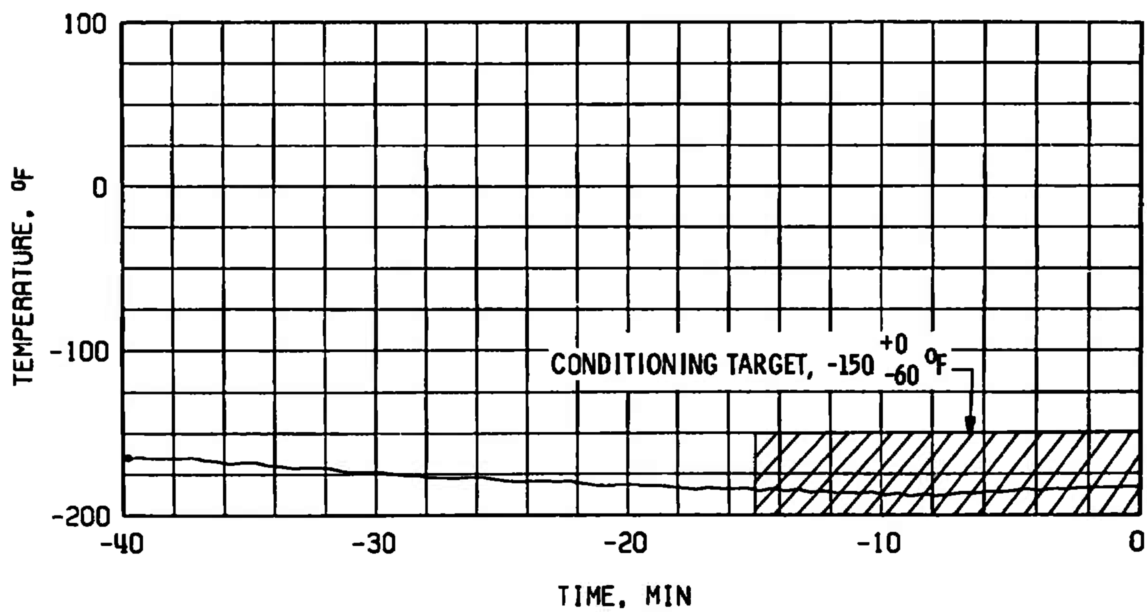


b. Crossover Duct, TFTD

Fig. 32 Thermal Conditioning History of Engine Components, Firing 15B



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 32 Concluded

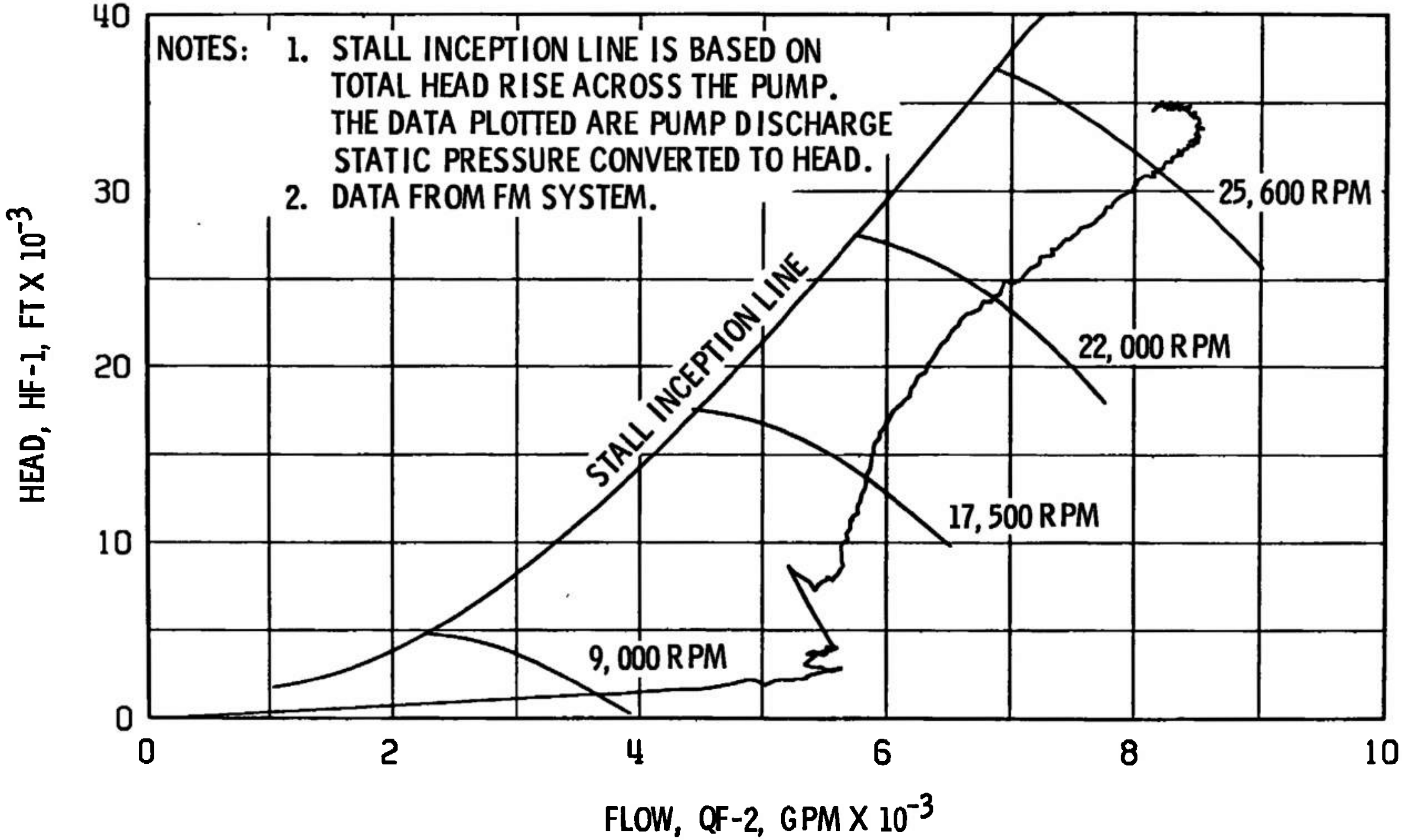


Fig. 33 Fuel Pump Start Transient Performance, Firing 15B

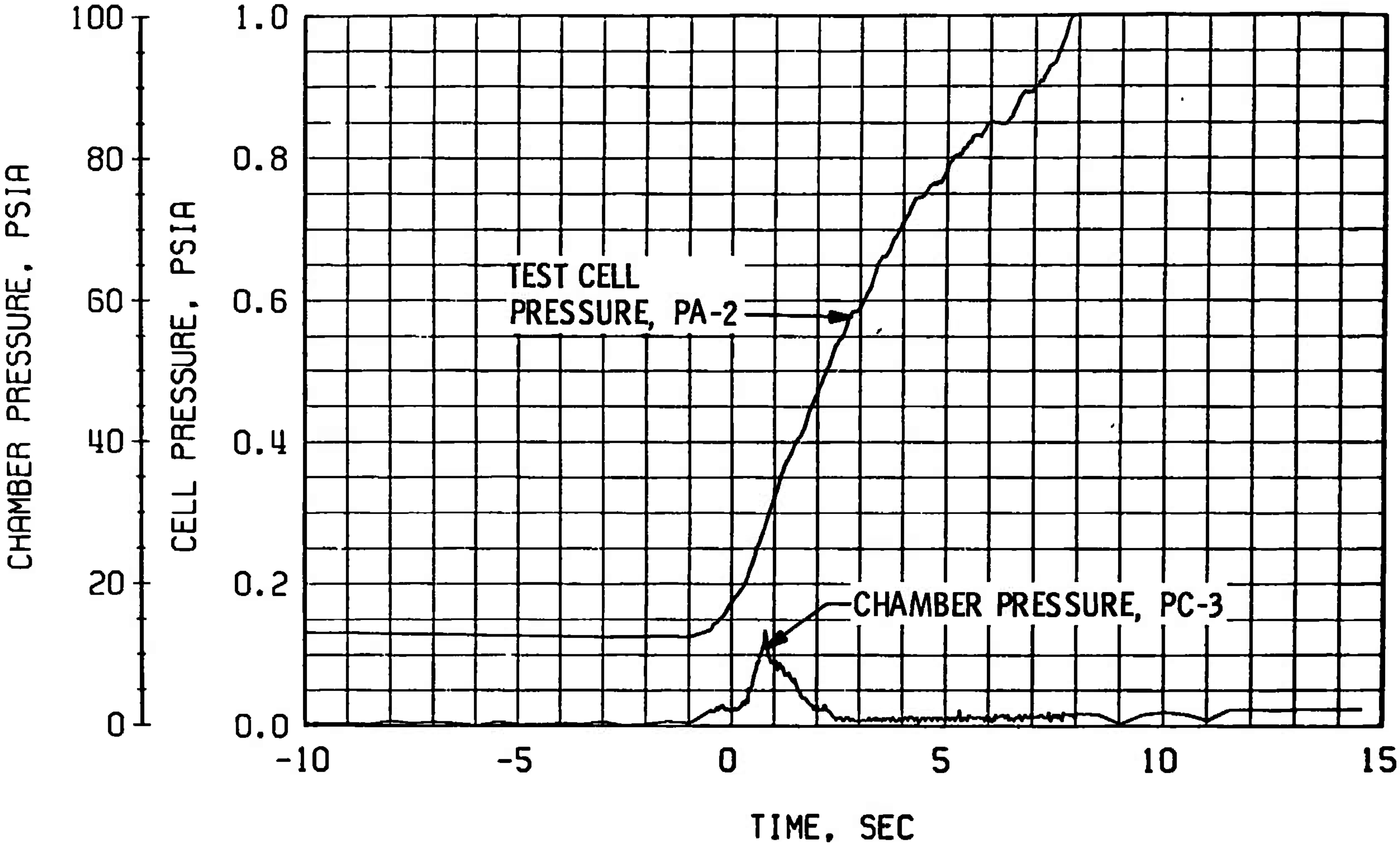
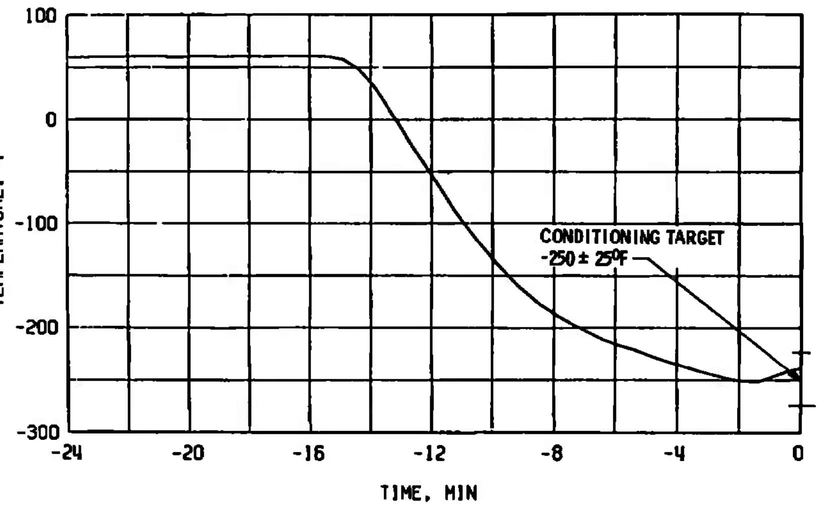
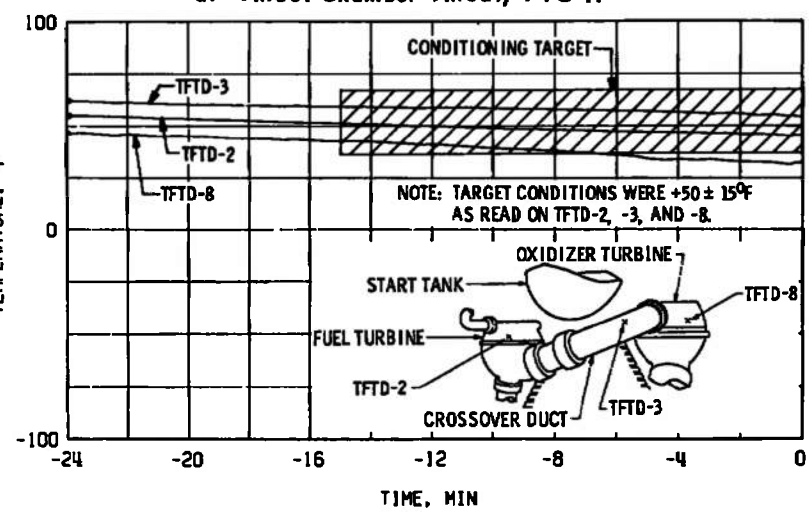


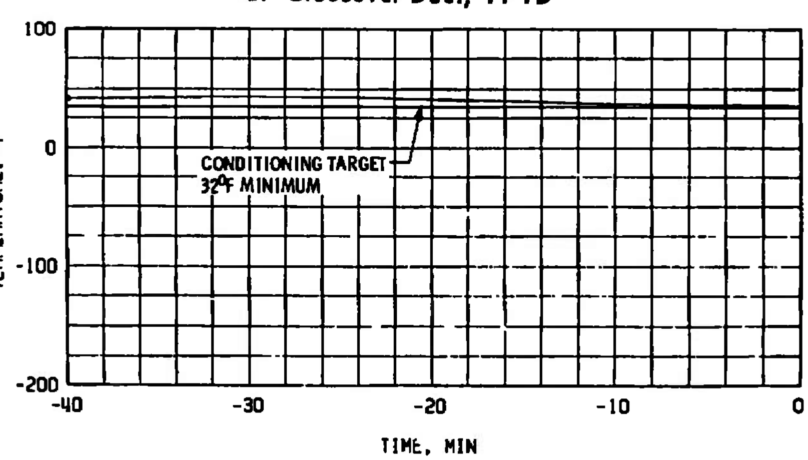
Fig. 34 Engine Ambient and Combustion Chamber Pressures, Firing 15E



a. Thrust Chamber Throat, TTC-1P

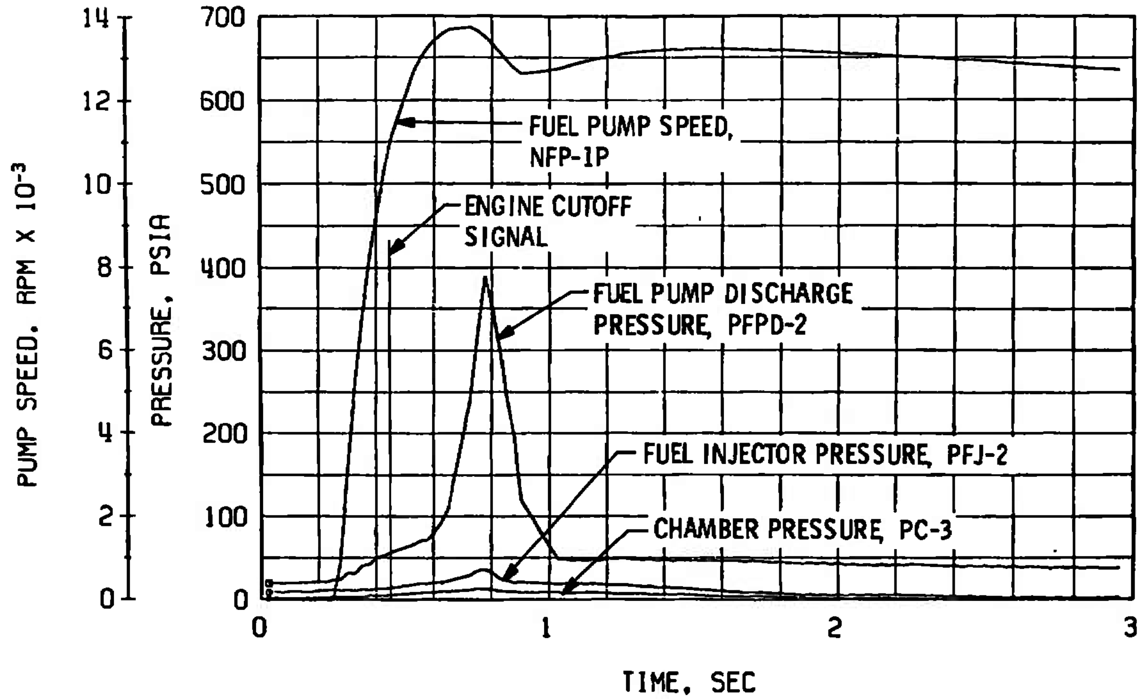


b. Crossover Duct, TFTD

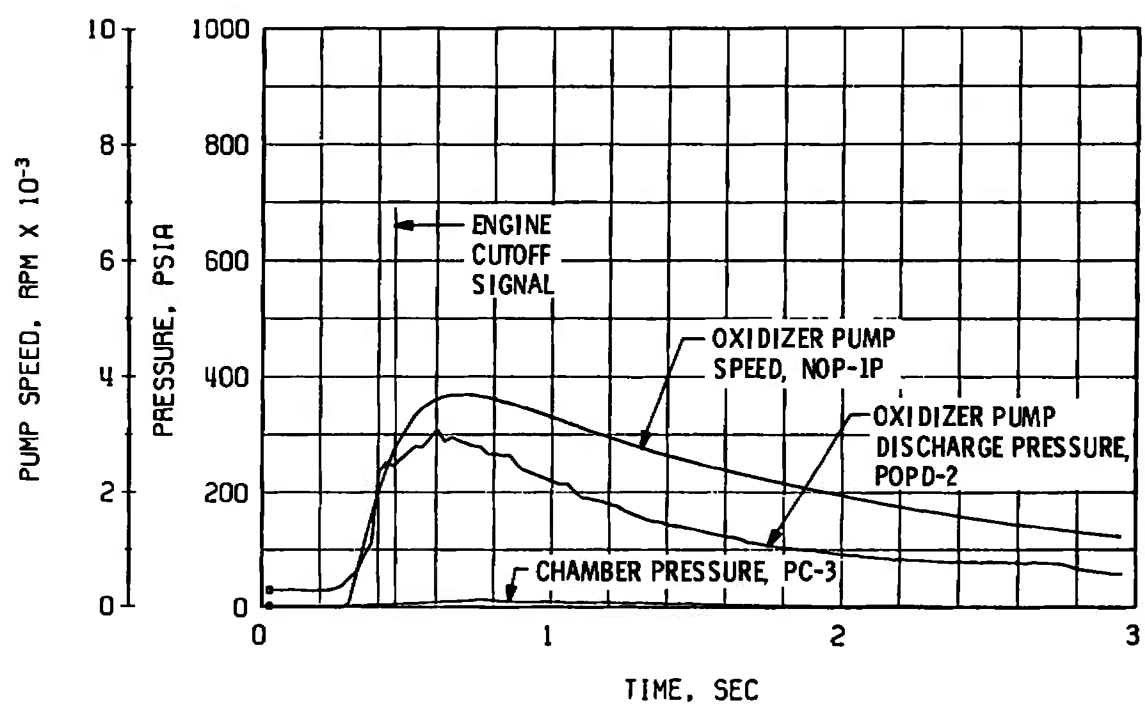


c. Start Tank Discharge Valve, TSTDVOC

Fig. 35 Thermal Conditioning History of Engine Components, Firing 15E



a. Thrust Chamber Fuel System, Start and Shutdown



b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 36 Engine Start and Shutdown Transient Operation, Firing 15E

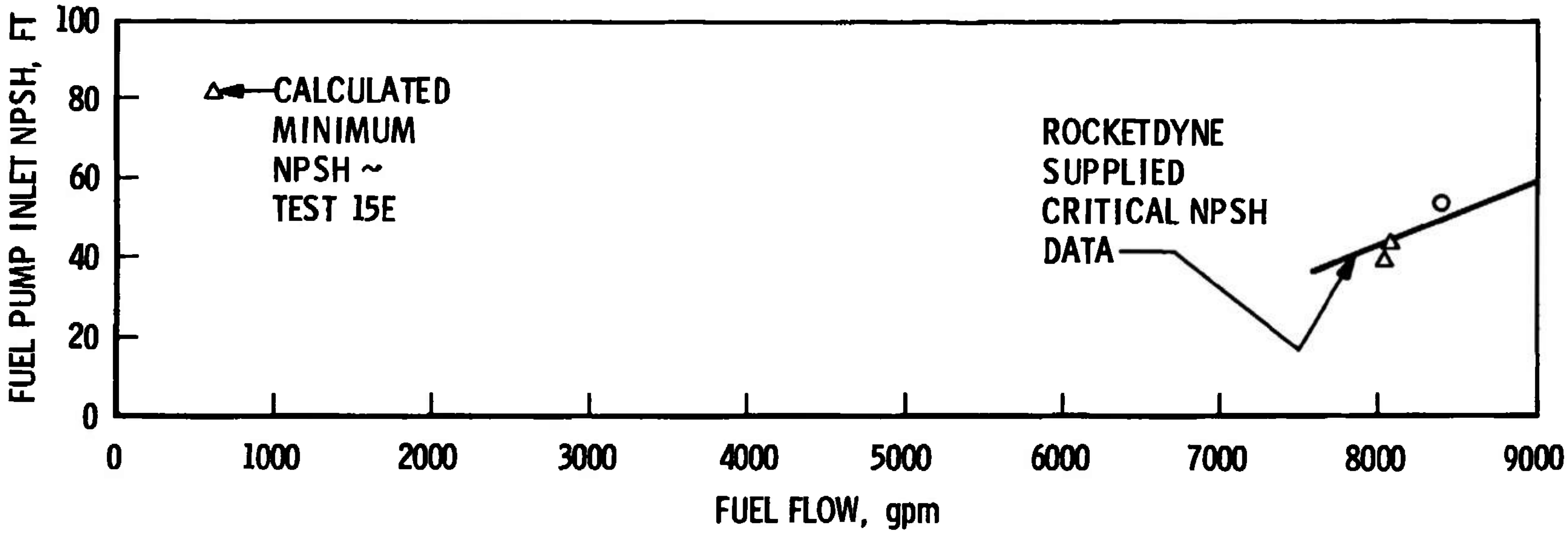


Fig. 37 Fuel Pump Net Positive Suction Head, Firing 15E

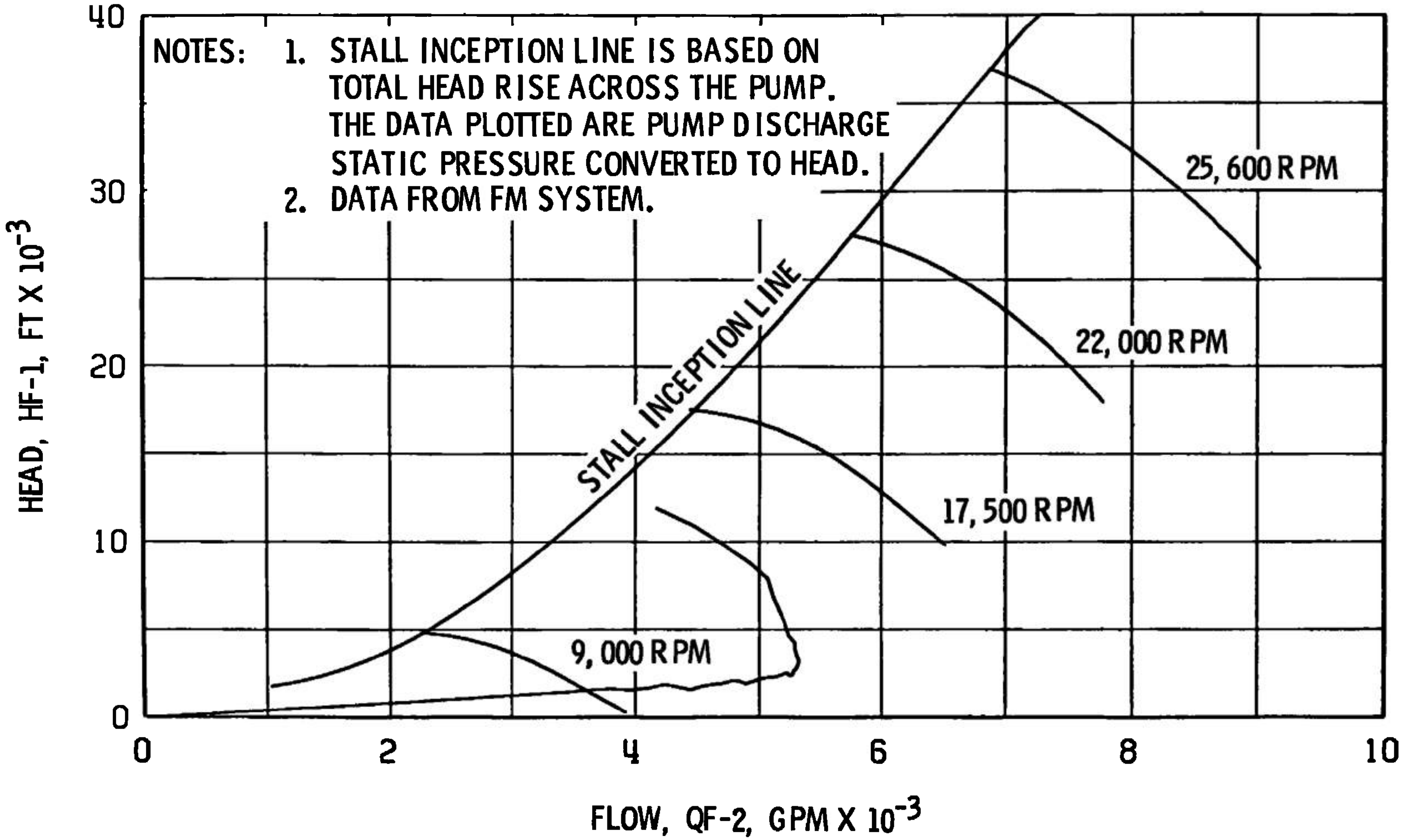
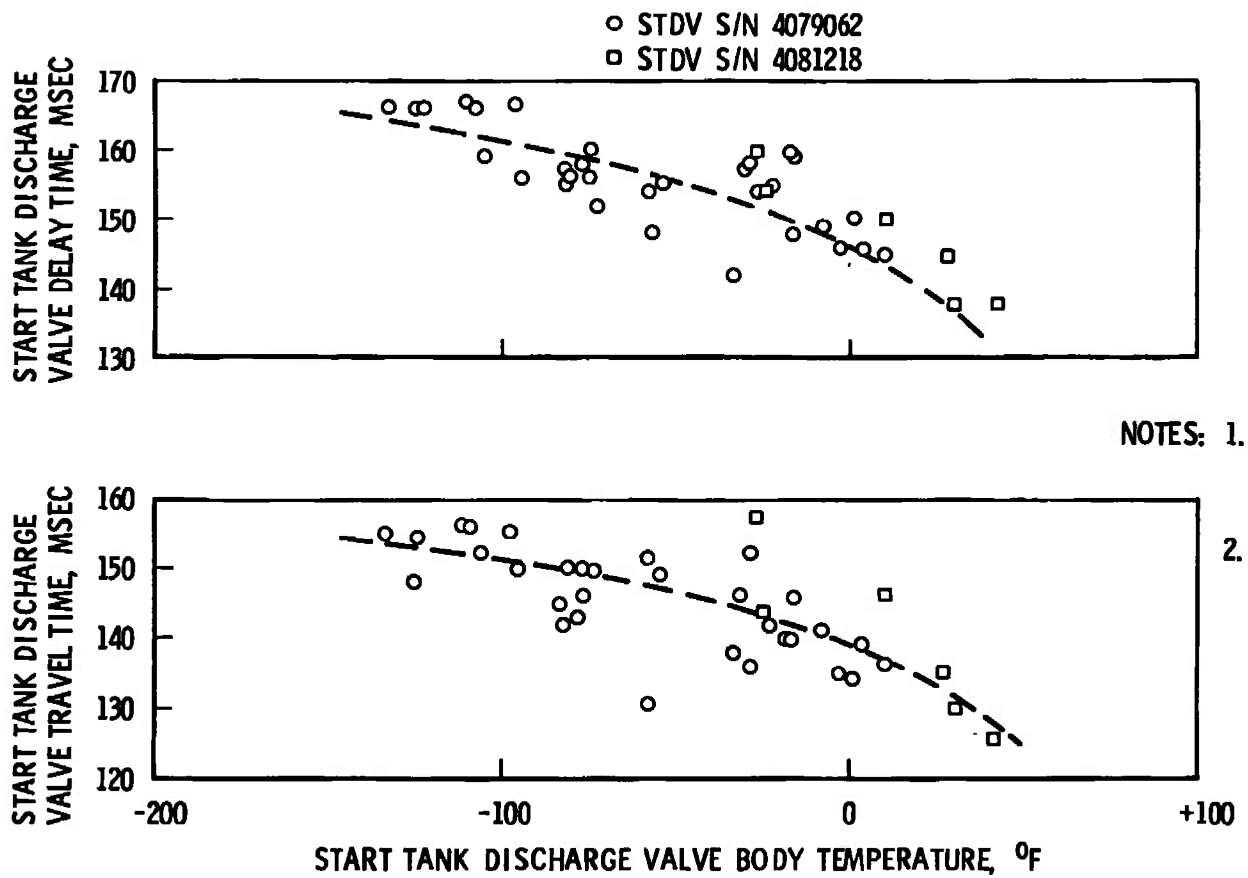


Fig. 38 Fuel Pump Start Transient Performance, Firing 15E



NOTES: 1. DATA TAKEN FROM TESTS J4-1801-01 THROUGH J4-1801-15
2. DATA REDUCED FROM OSCILLOGRAM

Fig. 39 Start Tank Discharge Valve Delay and Travel Times versus Temperature

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4072755
Thrust Chamber Injector Assembly	208021-11	4071421
Fuel Turbopump Assembly	459000-171	4078258
Oxidizer Turbopump Assembly	458175-71	6616135
Start Tank	303439	0038
Augmented Spark Igniter	206280-81	4078806
Gas Generator Fuel Injector and Combustor	308360-11	2008734
Gas Generator Oxidizer Injector and Poppet Assembly	303323	4076827
Helium Regulator Assembly	556948	4072709
Electrical Control Package	502670-11	4078604
Primary Flight Instrumentation Package	703685	4077391
Auxiliary Flight Instrumentation Package	703680	4077313
Main Fuel Valve	409120	4062472
Main Oxidizer Valve	409973	4077271
Gas Generator Control Valve	309040	4076768
Start Tank Discharge Valve	306875	4081218
Oxidizer Turbine Bypass Valve (Test 13)	409930	4079685
Oxidizer Turbine Bypass Valve (Test 14, 15)	409930	4081831
Propellant Utilization Valve	251351-11	4068732
Main-Stage Control Valve (Four-Way)	555767	8284307
Ignition Phase Control Valve (Four-Way)	555767	8284305
Helium Control Valve (Three-Way)	NA5-27273	340919
Start Tank Vent and Relief Valve	557818	4062234
Helium Tank Vent Valve	NA5-27273	340918
Fuel Bleed Valve	309034	4077233
Oxidizer Bleed Valve	309029	4076750
Augmented Spark Igniter Oxidizer Valve	308880	4089946
Pressure Actuated Shutdown Valve Assembly	557817	4067200
Pressure Actuated Purge Control Valve	557823	4075865
Start Tank Fill/Refill Valve	558000	4072899
Fuel Flowmeter	251225	4076564
Oxidizer Flowmeter	251216	4077137
Fuel Injector Temperature Transducer	NA5-27441	12350
Restartable Ignition Detect Probe	NA5-27298T2	324

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, in.	Date Effective	Comments
Gas Generator Fuel Supply Time	RD251-4107	0.468	*	
Gas Generator Oxidizer Supply Time	RD251-4106	0.268	*	
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.319	*	
Main Oxidizer Valve Closing Control	556443	0.0267	October 7, 1967	Nonthermostatic Orifice
Oxidizer Turbine Exhaust Manifold	RD251-9004	10.000	*	
Augmented Spark Igniter Oxidizer Supply Line	406361	0.150	October 20, 1967	

*Installed before engine delivery to AEDC

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-12 AND J4-1801-15)

Modification Number	Completion Date	Description of Modification
	Test J4-1801-12	10/17/67
RFD*-74-67	October 20, 1967	Augmented Spark Igniter Oxidizer Line Orifice Replacement Old: 0. 126 in. New: 0. 150 in.
RFD-69-67		Oxidizer Heat Exchanger Inlet Line Installed
RFD-73-67		Main Oxidizer Valve Replacement Old: 411039 x 4 New: 409973
RFD-72-67	October 23, 1967	Start Tank Discharge Valve Purge Manifold Installation
RFD-37-1-67 (Supplement)	October 23, 1967	Main Oxidizer Valve Second-Stage Actuator Conditioning System.
	Test J4-1801-13	10/24/67
None		
	Test J4-1801-14	11/1/67
RFD 6-1-67	November 3, 1967	Main Oxidizer Valve Closing Control Pressure Monitor and Installation

*RFD - Rocketdyne Field Directive

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1801-12 AND J4-1801-15)

Replacement	Completion Date	Comment Replaced
Test J4-1801-12 10/17/67		
UCR*-007315	October 18, 1967	Ignition Detector Set P/N 99-9026355 S/N 2006856
UCR-007311	October 18, 1967	Ignition Detect Probe P/N NA5-27298T2 S/N 324
UCR-007316	October 21, 1967	Oxidizer Dome Purge Check Valve P/N 554078 S/N 3764364
Test J4-1801-13 10/24/67		
UCR-007318	October 26, 1967	Oxidizer Turbine Bypass Valve P/N 409930
Test J4-1801-14 11/1/67		
UCR-007319	November 2, 1967	Augmented Spark Igniter Number 2 Spark Cable Schrader Valve Assembly P/N RD 284-1001-0001

*UCR - Unsatisfactory condition report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

		Time, min: t - 80, t - 70, t - 60, t - 50, t - 40, t - 30, t - 20, t - 10, t - 0, t + 10
Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 82 - 125 psia 50 - 200°F (Nominal) 6 scfm at Customer Connect	10 min Propellant Drop 2-min Minimum Following Recirculation 1 to 3 min
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Nitrogen; 400 ± 25 psig 50 - 200°F (Minimum) 230 scfm	15 min 1 sec (Supplied by Engine Helium Tank during Start and Cutoff Transients)
Oxidizer Dome (Facility Line to Port CO3A)	Nitrogen; 400 - 450 psig 100 - 200°F (Nominal) 200 scfm	45 min On at Engine Cutoff 10 min
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 400 ± 25 psig Ambient Temperature 2600 - 7000 scfm	15 min Main-Stage Operation (Supplied by Engine Helium Tank)
Thrust Chamber Jacket (Customer Connect) Panel	Helium; 40 - 60 psig 50 - 200°F (Nominal) 60 scfm	In Addition to 15 min
	Helium; 12 - 14 psig 50 - 200°F (Nominal) 10 scfm	On at Engine Cutoff 10 min
Thrust Chamber Temperature Conditioning	Helium; 1000 psig -300°F to Ambient 10 - 20 lb_m/min	15 min
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia -298 to -280°F Fuel; 28 to 46 psia -424 to -416°F	
Hydrogen Stsrt Tank and Helium Tank Pressure snd Temperature Conditioning	Hydrogen; 1200 to 1400 psia -300 to -140°F Helium; 1700 to 3250 psia -300 to -140°F	46 min
Crossover Duct Temperature Conditioning	Helium; -300°F to Ambient	1
Start Tank Discharge Valve Temperature Conditioning	Helium; Ambient	

[1]Conditioning temperature to be maintained for the last 30 min of prefire.

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J4-1601-		15A Target	15A Actual	15B Target	15B Actual	14A Target	14A Actual	13A Target	13A Actual	13B Target	13B Actual	15E Target	15E Actual
Firing Date/Time of Day, hr		10-24-67	10:23	10-24-67	11:59	10-31-67	15:57	11-7-67	10:54	11-7-67	13:18	11-7-67	14:26
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	98,000	100,000	106,000	100,000	108,000	100,000	100,000	100,000	103,000	100,000	107,000
Firing Duration, sec①		30.000	30.075	5.000	5.089	30.000	30.072	30.000	30.072	5.000	5.087	0.440	0.446
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	25.5^{+1}_{-0}	27.6	25.5^{+1}_{-0}	26.7	25.5^{+1}_{-0}	25.8	25.5^{+1}_{-0}	25.6	25.5^{+1}_{-0}	28.0	23.5^{+1}_{-0}	24.1
	Temperature, °F	-421.4 ± 0.4	-421.8	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-421.2	-421.4 ± 0.4	-421.1	-421.4 ± 0.4	-421.2
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	33.0^{+1}_{-0}	55.7	43.0 ± 1	45.3	25^{+1}_{-0}	23.5	32.0^{+1}_{-0}	33.6	45.1 ± 1	45.4	28.0 ± 1	28.7
	Temperature, °F	-294.5 ± 0.4	-294.9	-294.5 ± 0.4	-294.9	-294.5 ± 0.4	-294.6	-294.3 ± 0.4	-294.8	-294.2 ± 0.4	-294.7	-295.0 ± 0.4	-293.1
Start Tank Conditions at Engine Start	Pressure, psia	1250 ± 10	1245	1400 ± 10	1401	1250 ± 10	1233	1250 ± 10	1245	1400 ± 10	1296	1400 ± 10	1405
	Temperature, °F	-140 ± 10	-132	-240 ± 10	-244	-140 ± 10	-135	-140 ± 10	-127	-240 ± 10	-226	-240 ± 10	-240
Helium Tank Conditions at Engine Start	Pressure, psia	---	2213	---	2371	---	2571	---	2846	---	2744	---	2755
	Temperature, °F	---	-132	---	-238	---	-135	---	-138	---	-224	---	-236
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat, TTC-1P	-250 ± 25	-243	-150^{+20}_{-10}	-142	-250 ± 25	-249	-250 ± 25	-255	-250 ± 25	-227	-250 ± 25	-259
	Average	---	-263	---	-150	---	-264	---	-244	---	-260	---	-251
Crossover Duct Temperature at Engine Start, °F②	TFTD-2	-50 ± 15	-74	+50 ± 25	27	-50 ± 15	-70	-30 ± 15	-89	+50 ± 13	24	+30 ± 13	45
	TFTD-2	-50 ± 15	-62	+50 ± 25	28	-50 ± 15	-48	-50 ± 15	-38	+50 ± 15	54	+50 ± 15	54
	TFTD-8	-50 ± 15	-88	+50 ± 23	38	-50 ± 13	-85	-50 ± 15	-68	+30 ± 15	29	+50 ± 15	32
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F		---	-8	---	+7	---	-26	---	-50	---	-24	---	-30
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F		-80^{+0}_{-20}	-80	-180^{+0}_{-80}	-175	-60^{+20}_{-0}	-79	-40^{+0}_{-20}	-60	-150^{+0}_{-80}	-184	---	-173
Fuel Lead Time, sec①		1.000	1.007	1.000	1.010	1.000	1.011	1.000	1.006	1.000	1.001	1.000	1.001
Propellant in Engine Time, min		40	79	60	60	40	47	20	48	80	160	20	71
Propellant Recirculation Time, min		10	11	10	11	10	10	10	10	10	11	10	10
Start Sequence		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-2A	---	29	---	-11	---	+14	---	+17	---	+5	---	+8
Start Tank Discharge Valve Body Temperature at Engine Start, °F		32 (min)	42	32 (min)	27	22 (min)	30	32 (min)	+29	32 (min)	+31	32 (min)	+34
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from $t_0$①		--- / ---	25 / 1.043	--- / ---	7 / 0.980	--- / ---	129 / 1.024	--- / ---	110 / 1.030	--- / ---	29 / 0.972	--- / ---	0 / ---
Gas Generator Outlet Temperature, °F	Initial Peak	---	1435	---	1394	---	1163	---	1238	---	1712	---	---
	Second Peak	---	---	---	1511	---	---	---	---	---	---	---	---
Thrust Chamber Ignition Time, sec (Ref. t_0) (P_c = 100 psia)①		---	1.042	---	0.880	---	1.059	---	1.024	---	0.976	---	---
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)①		---	0.962	---	1.187	---	1.020	---	1.004	---	1.130	---	---
Main-Stage Pressure No. 2 "O.K.", sec (Ref. t_0)①		---	1.863	---	1.697	---	1.828	---	1.779	---	1.650	---	---
550-psia Chamber Pressure Attained, sec (Ref. t_0)		---	2.243	---	2.029	---	2.174	---	2.090	---	1.954	---	---
Propellant Utilization Valve Position at Engine Start, deg / Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Null / ---	Null / ---	Null / Closed	Null / ---	Null / Closed	Null / Closed	Null / ---	Null / ---	Null / ---	Null / ---

Notes: ①Data reduced from oscillogram
②Component conditioning to be maintained within limits for last 15 min prior to engine start

TABLE VII
ENGINE VALVE TIMINGS

	Firing Number J4-1801-	Start																							
		Start Tank Discharge Valve			Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gaa Generator Fuel Poppet			Oxidizer Turbine Bypass Valve			Start Tank Discharge Valve		
		Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, aec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, acc	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, aec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, aec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sac
	13A	0.0	0.137	0.125	-1.007	0.057	0.072	0.452	0.057	0.060	0.452	0.530	1.875	0.452	0.112	0.030	0.452	0.181	0.078	0.452	0.228	0.339	0.452	0.090	0.243
	13B	0.0	0.145	0.135	-1.010	0.057	0.075	0.440	0.060	0.089	0.440	0.735	2.123	0.440	0.127	0.023	0.440	0.202	0.075	0.440	0.223	0.514	0.440	0.088	0.248
	14A	0.0	0.137	0.130	-1.010	0.056	0.087	0.450	0.055	0.055	0.450	0.570	1.888	0.450	0.108	0.028	0.450	0.180	0.077	0.450	0.220	0.298	0.450	0.080	0.242
	15A	0.0	0.140	0.130	-1.006	0.056	0.063	0.448	0.055	0.057	0.448	0.547	1.803	0.448	0.108	0.028	0.448	0.182	0.079	0.448	0.228	0.290	0.448	0.080	0.245
	15B	0.0	0.145	0.130	-1.001	0.058	0.075	0.448	0.062	0.060	0.448	0.683	2.154	0.448	0.120	0.030	0.448	0.184	0.078	0.448	0.220	0.282	0.448	0.086	0.243
	15E	0.0	0.142	0.138	-1.001	0.059	0.078	0.445	N/A	N/A	0.445	N/A	N/A	0.445	N/A	N/A	0.445	N/A	N/A	0.445	N/A	N/A	0.445	2.922	0.841
Final Sequence	13	0.0	0.100	0.110	-1.008	0.045	0.070	0.451	0.050	0.058	0.451	0.508	1.385	0.451	0.088	0.030	0.451	0.138	0.069	0.451	0.200	0.305	0.451	0.081	0.243
	14	0.0	0.100	0.109	-1.010	0.042	0.070	0.448	0.051	0.058	0.449	0.520	1.403	0.449	0.088	0.031	0.449	0.142	0.065	0.448	0.207	0.275	0.449	0.082	0.243
	15	0.0	0.102	0.110	-1.000	0.044	0.072	0.450	0.048	0.052	0.450	0.516	1.418	0.450	0.083	0.034	0.450	0.140	0.065	0.450	0.200	0.289	0.450	0.090	0.252

	Firing Number J4-1801-	Shutdown														
		Main Fuel Valve			Main Oxidizer Valve			Gaa Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
		Tima of Closing Signal	Valve Delay Time, aec	Valve Closing Time, aec	Time of Closing Signal	Valve Delay Time, aec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, aec	Valve Closing Time, aec	Time of Closing Signal	Valva Delay Tima, aec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Tima, sec	Valve Opening Time, sec
	13A	30.075	0.135	0.342	30.075	0.064	0.168	30.075	0.055	0.028	30.075	0.033	0.012	30.075	0.371	0.466
	13B	5.088	0.139	0.357	5.089	0.057	0.180	5.089	0.058	0.020	5.089	0.031	0.023	5.088	0.213	0.474
	14A	30.072	0.128	0.325	30.072	0.142	0.237	30.072	0.053	0.020	30.072	0.030	0.014	30.072	0.204	0.565
	15A	30.073	0.131	0.318	30.073	0.061	0.180	30.073	0.055	0.024	30.073	0.030	0.015	30.073	0.240	0.440
	15B	5.087	0.134	0.369	5.087	0.053	0.193	5.087	0.058	0.025	5.087	0.031	0.015	5.087	0.214	0.400
	15E	0.446	0.110	0.307	0.448	N/A	N/A	0.446	N/A	N/A	0.448	N/A	N/A	0.446	N/A	N/A
Final Sequence	13	4.360	0.083	0.238	4.360	0.047	0.128	4.360	0.078	0.020	4.360	0.053	0.026	4.380	0.183	0.670
	14	8.078	0.084	0.240	8.078	0.050	0.130	8.078	0.080	0.024	8.078	0.056	0.018	8.078	0.205	0.578
	15	6.720	0.086	0.255	6.720	0.052	0.123	8.720	0.079	0.030	8.720	0.052	0.020	6.720	0.210	0.535

Notes: 1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valva movement after the valve "open" or valve "closed" solenoid haa been energized.
3. Final sequence check ia conducted without propellanta and within 12 houra prior to testing.
4. Data reduced from oscillogram

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1801-		13A		14A		15A	
		Site	Normalized	Site	Normalized	Site	Normalized
Overall Engine Performance	Thrust, lb_f	225, 391	224, 296	199, 071	198, 277	232, 748	231, 232
	Chamber Pressure, psia	758	751	675	670	780	772
	Mixture Ratio	5. 548	5. 553	4. 992	5. 014	5. 551	5. 541
	Fuel Weight Flow, lb_m/sec	81. 13	80. 36	78. 17	77. 33	82. 46	81. 71
	Oxidizer Weight Flow, lb_m/sec	450. 12	446. 23	390. 23	387. 72	457. 72	452. 76
	Total Weight Flow, lb_m/sec	531. 25	526. 59	468. 40	465. 05	540. 18	534. 47
Thrust Chamber Performance	Mixture Ratio	5. 750	5. 758	5. 169	5. 194	5. 748	5. 741
	Total Weight Flow, lb_m/sec	524. 60	519. 98	462. 33	459. 00	533. 40	527. 74
	Characteristic Velocity, ft/sec	7907	7904	7992	7985	8008	8009
Fuel Turbopump Performance	Pump Efficiency, percent	75. 2	75. 2	74. 5	74. 5	75. 1	75. 1
	Pump Speed, rpm	26, 272	26, 124	25, 228	25, 102	26, 809	26, 640
	Turbine Efficiency, percent	59. 5	59. 4	58. 4	58. 3	60. 5	60. 4
	Turbine Pressure Ratio	7. 24	7. 24	7. 10	7. 10	7. 16	7. 16
	Turbine Inlet Temperature, °F	1213	1198	1100	1090	1268	1250
	Turbine Weight Flow, lb_m/sec	6. 65	6. 62	6. 08	6. 05	6. 78	6. 74
Oxidizer Turbopump Performance	Pump Efficiency, percent	80. 3	80. 2	81. 1	81. 0	80. 3	80. 2
	Pump Speed, rpm	8528	8477	8035	7985	8676	8623
	Turbine Efficiency, percent	47. 8	47. 7	47. 1	46. 9	47. 9	47. 8
	Turbine Pressure Ratio	2. 64	2. 64	2. 63	2. 63	2. 67	2. 66
	Turbine Inlet Temperature, °F	783	773	701	694	826	813
	Turbine Weight Flow, lb_m/sec	6. 0	5. 98	5. 48	5. 46	6. 11	6. 08
Gas Generator Performance	Mixture Ratio	0. 947	0. 939	0. 881	0. 875	0. 980	0. 970
	Chamber Pressure, psia	644	640	578	575	662	657

Note: 1. Site data is calculated from test data.
2. Normalized data is corrected to standard pump inlet and engine ambient pressure conditions.
3. Input data is test data averaged from 29 to 30 sec.
4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC test J4-1801-13, 14, and 15 is tabulated in Table III-I. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
LIST OF ENGINE INSTRUMENTATION

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFJT	Fuel Injector Temperature OK		On/Off	x		x		
EFPVC/O	Fuel Pre-Valve Closed/Open Limit		Closed/Open	x		x		
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Mainstage Control Solenoid		On/Off	x		x		
EMP-1	Mainstage Pressure No. 1		On/Off	x		x		
EMP-2	Mainstage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Pre-Valve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Pre-Valve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No No. 2		On/Off			x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0-9000	x		x		
QF-2	Fuel	PFFA	0-9000	x	x	x		
QF-2SD	Fuel Flow Stall Approach Monitor		0-9000	x		x		
QFRP	Fuel Recirculation		0-160	x				
QO-1A	Oxidizer	POF	0-3000	x		x		
QO-2	Oxidizer	POFA	0-3000	x	x	x		
QORP	Oxidizer Recirculation		0-50	x		x		
	Forces		lb_f					
FSP-1	Side Load (Pitch)		±20, 000	x		x		
FSY-1	Side Load (Yaw)		±20, 000	x		x		
	Heat Flux		$\frac{w}{Sr - cm^2}$					
RTCEP	Radiation Thrust Chamber Exhaust Plume		0-7	x				
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure		amp					
PA1	Test Cell		0-0.5	x		x		
PA2	Test Cell		0-1.0	x	x			
PA3	Test Cell		0-5.0	x			x	
PC-1P	Thrust Chamber	CG1	0-1000	x			x	
PC-3	Thrust Chamber	CG1A	0-1000	x	x	x		
PCGG-1P	Gas Generator Chamber Pressure		0-1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0-1000	x				
PFASIJ	Augmented Spark Igniter Fuel Injection		0-1000	x				
PFJ-1A	Main Fuel Injection	CF2	0-1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0-1000	x	x			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0-1000	x				
PFJGG-2	Gas Generatnr Fuel Injection	GF4	0-1000	x		x		
PFMI	Fuel Jacket Inlet Manifold	CF1	0-2000	x				
PFOI-1A	Fuel Tapoff Orifice Outlet	HF2	0-1000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0-1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0-1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0-1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0-100	x				x
PFPI-2	Fuel Pump Inlet		0-200	x				x
PFPI-3	Fuel Pump Inlet		0-200		x	x		
PFPS-1P	Fuel Pump Interstage	PF6	0-200	x				
PFRPO	Fuel Recirculation Pump Outlet		0-60	x				
PFRPR	Fuel Recirculation Pump Return		0-50	x				
PFST-1P	Fuel Start Tank	TF1	0-1500	x		x		
PFST-2	Fuel Start Tank	TF1	0-1500	x				x
PFUT	Fuel Tank Ullage		0-100	x				
PFVI	Fuel Tank Pressurization Line Nozzle Inlet		0-1000	x				
PFVL	Fuel Tank Pressurization Line Nozzle Throat		0-1000	x				
PHECMO	Pneumatic Control Module Outlet		0-750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0-150	x				
PHES	Helium Supply		0-5000	x				
PHET-1P	Helium Tank	NN1	0-3500	x		x		
PHET-2	Helium Tank	NN1	0-3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0-750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0-50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0-2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0-1000	x				
POJ-2	Main Oxidizer Injection	CO3A	0-1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0-1000	x		x		
POJGG-2	Gas Generator Oxidizer Injection	GO5	0-1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0-500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0-1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0-1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0-100	x				x
POPI-2	Oxidizer Pump Inlet		0-200	x				x
POPI-3	Oxidizer Pump Inlet		0-100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0-50	x				

TABLE III-1 (Continued)

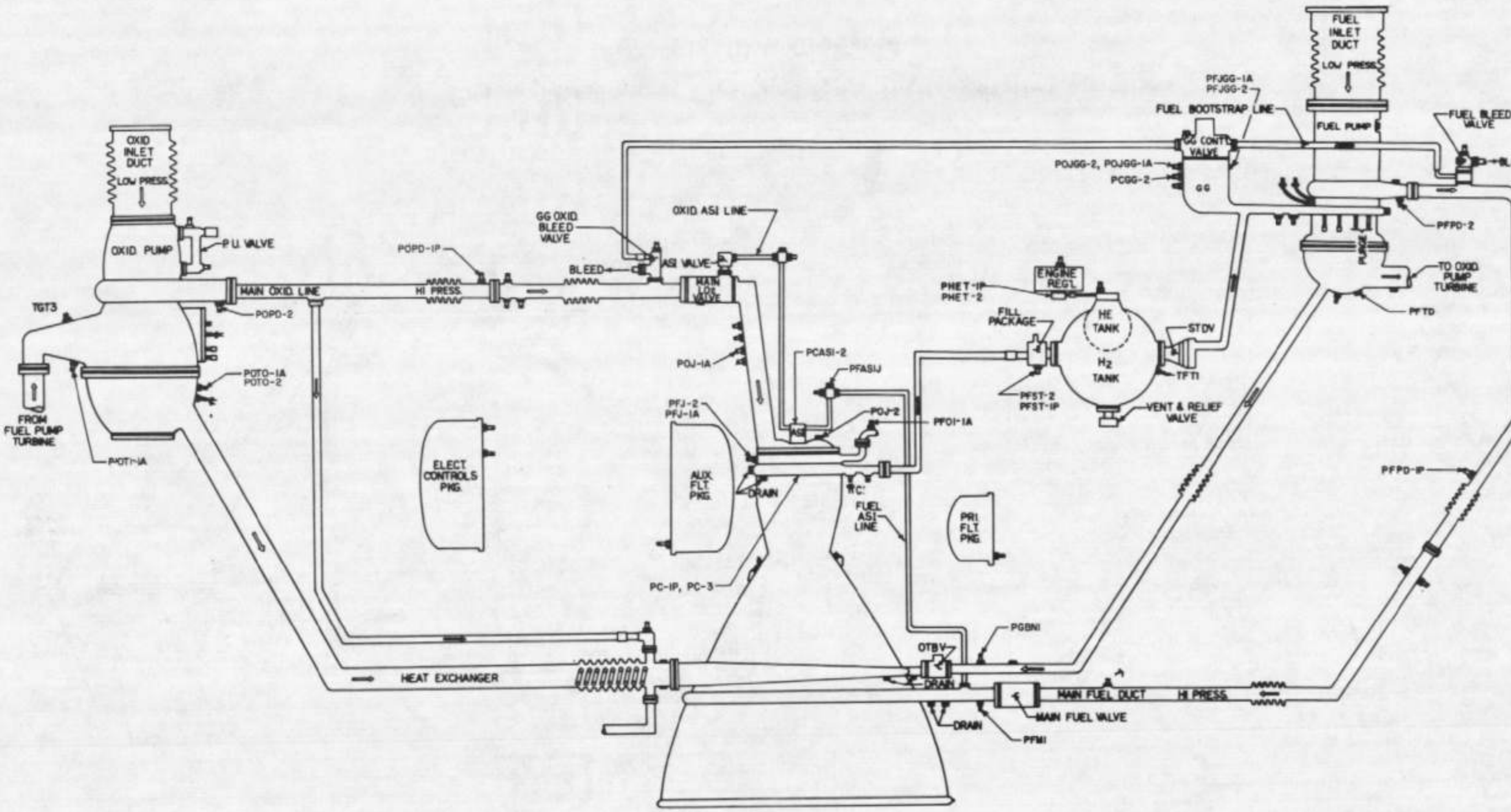
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure		psia					
PORPO	Oxidizer Recirculation Pump Outlet		0-115	x				
PORPR	Oxidizer Recirculation Pump Return		0-100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0-200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0-100	x				
POUT	Oxidizer Tank Ullage		0-100	x				
POVCC	Main Oxidizer Valve Closing Control		0-500	x	x			
POVI	Oxidizer Tank-Repressurization Line Nozzle Inlet		0-1000	x				
POVL	Oxidizer Tank-Repressurization Line Nozzle Throat		0-1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0-1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0-500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0-100	x				
PTCP	Thrust Chamber Purge		0-15	x				
PTPP	Turbopump and Gas Generator Purge		0-250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0-30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0-15,000	x				
NOP-1P	Oxidizer Pump	POV	0-12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0-15,000	x				
	Temperatures		°F					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBPM	Bypass Manifold		-325 to +200	x				
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TECP-1P	Electrical Controls Package	NSTIA	-300 to +200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to +100	x				
TFASIL-1	Augmented Spark Igniter Line		-300 to +200	x			x	
TFASIL-2	Augmented Spark Igniter Line		-300 to +300	x			x	
TFBV-1A	Fuel Bleed Valve	GFTI	-425 to -375	x				
TFD-I	Fire Detection		0 to 1000	x			x	
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFTI	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-2	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFTI	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-4R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTI-1P	Fuel Turbine Inlet	TFT1	0 to 1800	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x	x	x		
THET-1P	Helium Tank	NNT1	-350 to +100	x				x
TNODP	LO_2 Dome Purge		0 to -300	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2A	Oxidizer Boorstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to +250	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Pressurization Line Nozzle Throat		-300 to +100	x				
TPCC	Prechill Controller		-425 to -300	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to +500	x				
TSC2-7	Thrust Chamber Skin		-300 to +500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500					
TSC2-9	Thrust Chamber Skin		-300 to +500	x				
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to +500	x				
TSC2-15	Thrust Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				

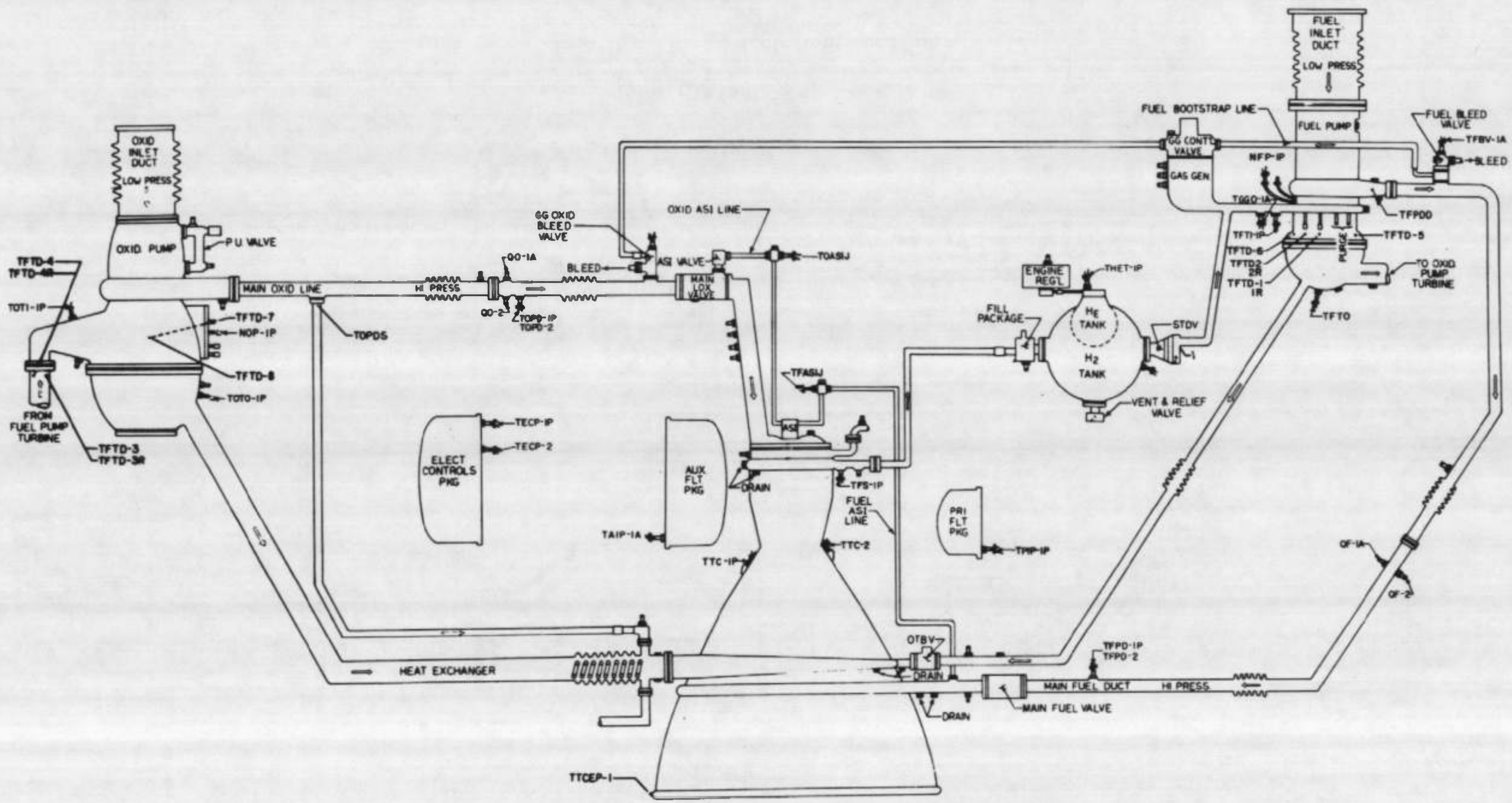
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x				
TSTC	Start Tank Conditioning		-325 to +150	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x				
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x				
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TTCEP-2	Thrust Chamber Exit		-365 to +380	x				
TXOC	Crossover Duct Conditioning		-325 to +200	x				
	Vibrations		g's					
UFPR	Fuel Pump Radial 90 deg		±200		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		v					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				



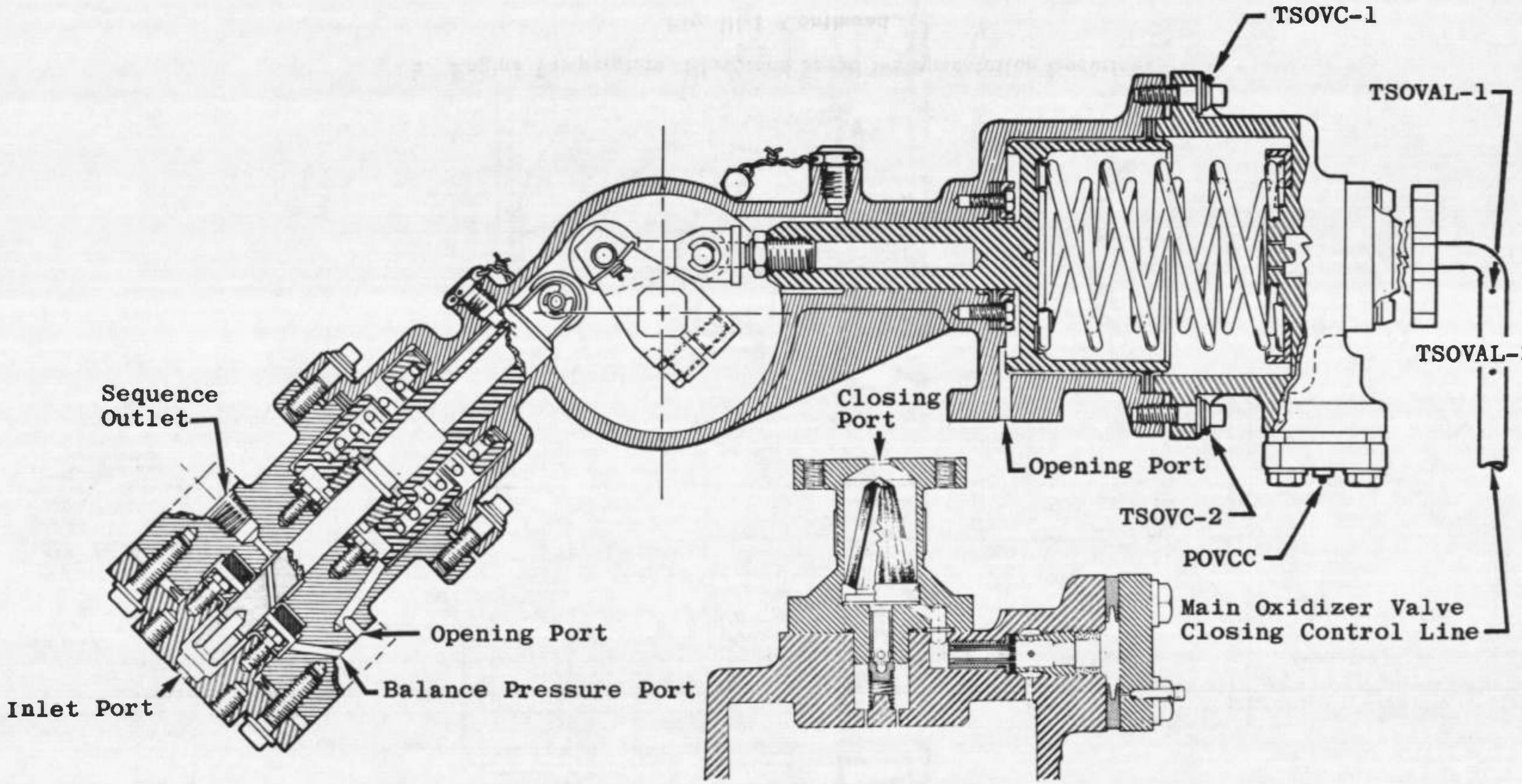
a. Engine Pressure Tap Locations

Fig. III-1 Instrumentation Locations



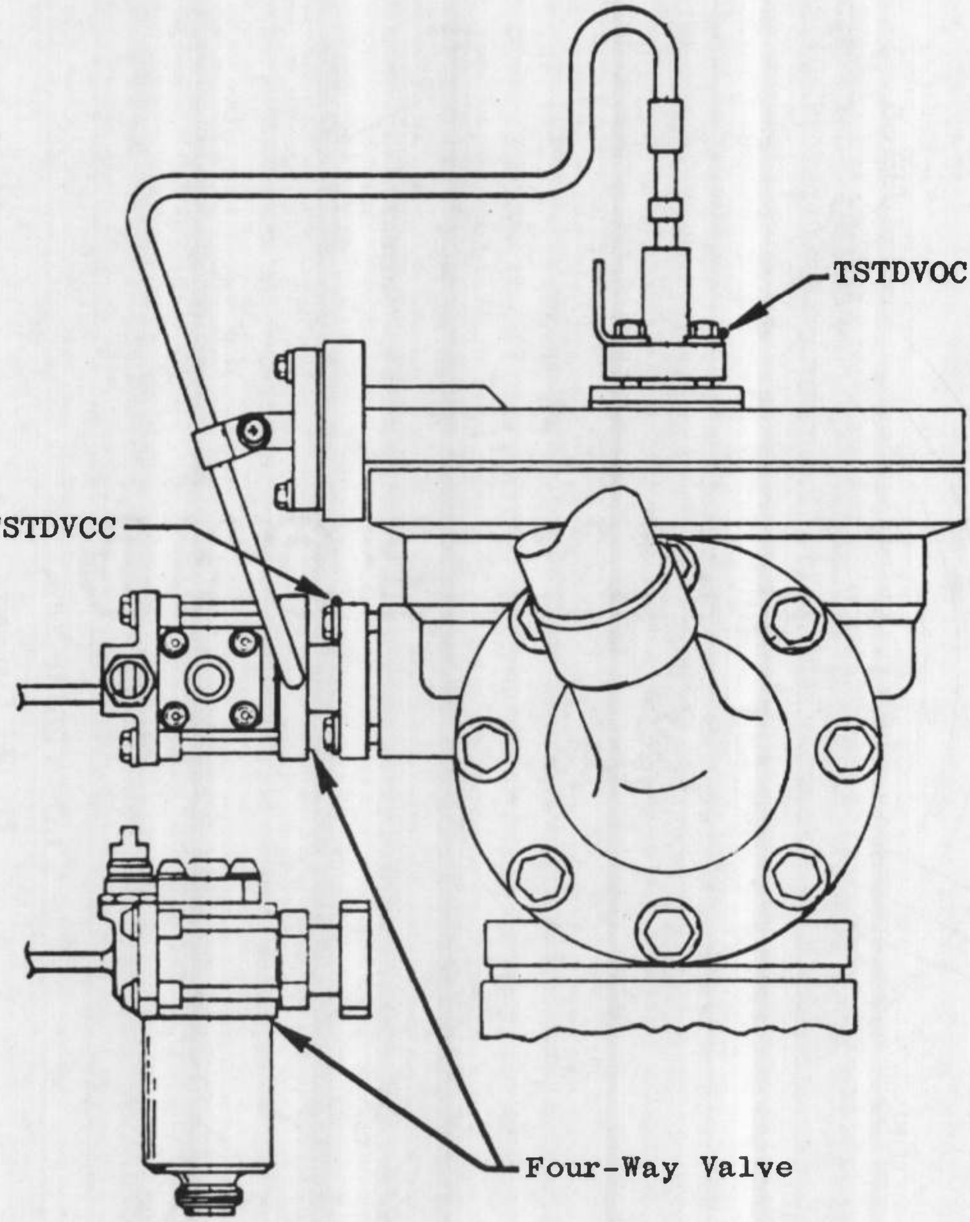
b. Engine Temperature, Flow, and Speed Instrumentation Locations

Fig. III-1 Continued



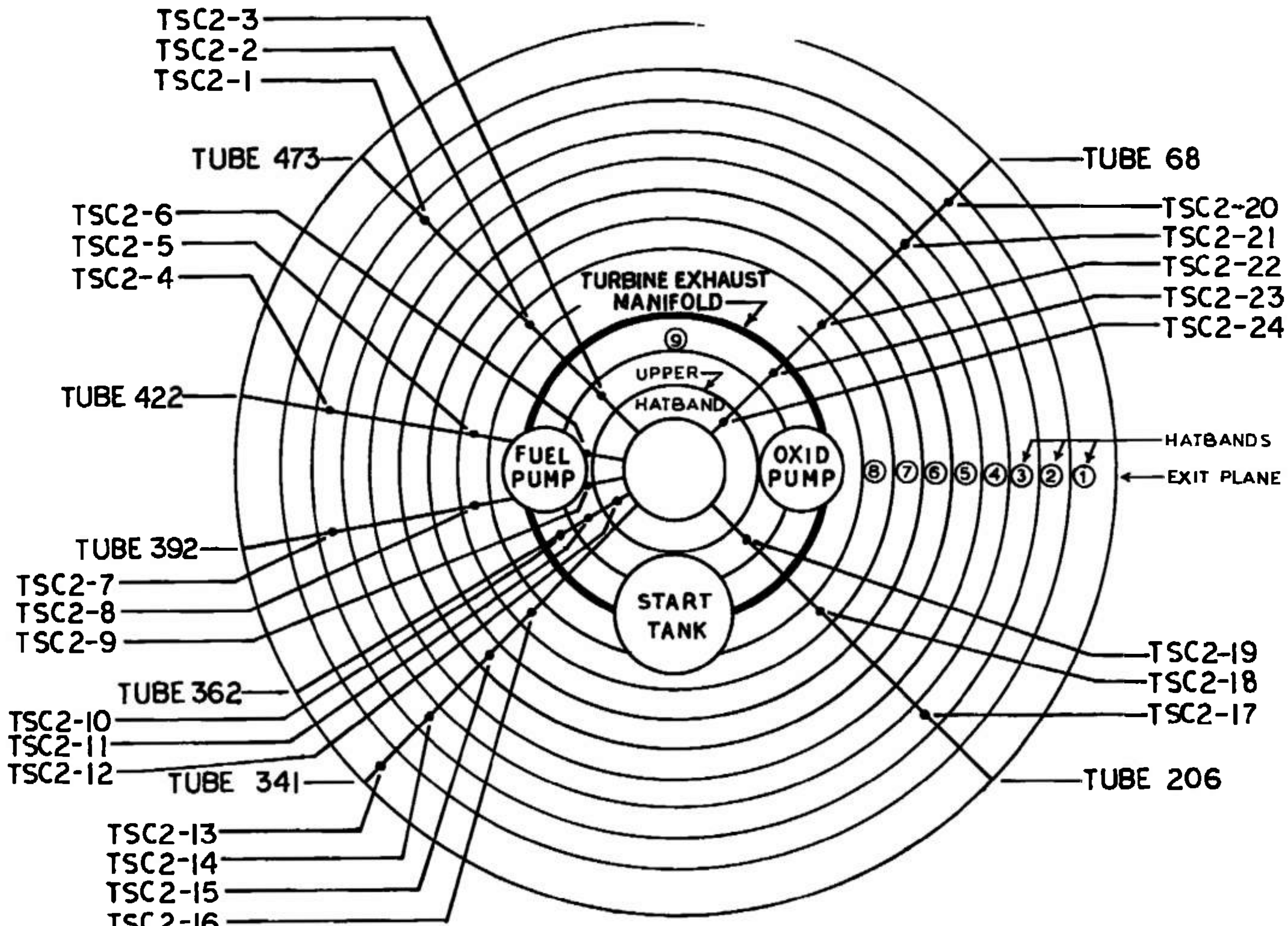
c. Main Oxidizer Valve

Fig. III-1 Continued



d. Start Tank Discharge Valve

Fig. III-1 Continued



VIEW LOOKING AFT

e. Thrust Chamber

Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, v
10	Propellant Utilization Valve Position, v
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is estimated from gas generator chamber pressure.

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FIT	Fuel turbine inlet
FM	Fuel measured
FY	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
T_O	Turbine oxidizer
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

$$W_E = W_{EO} + W_{EF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = 0.8 \text{ lb/sec}$$

$$W_{XF} = 1.8 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF}\ A_{TIF}\ K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

$$W_C = W_{CO} + W_{CF}$$

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7\ P_c\ A_t}{W_C}$$

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$

$$P_{IF} = 30 \text{ psia}$$

$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$

$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$

$$T_{IO} = -295.212\,°F$$

$$T_{IF} = -422.547\,°F$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$

$$K_4 = 144$$

$$\rho = \text{National Bureau of Standards Values f (P,T)}$$

Fuel

$$H_f = 778.16\, \Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P,T)$$

$$h_{IF} = f(P,T)$$

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\, Y_O$$

$$\eta_{OC} = K_{40} \left(\frac{Q_{PO}}{N_O}\right)^2 + K_{50} \left(\frac{Q_{PO}}{N_O}\right) + K_{60}$$

$$K_{40} = 5.0526$$

$$K_{50} = 3.8611$$

$$K_{60} = 0.0733$$

$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} \; H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO} \; \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B \left(P_{OO}\right)$$

$$A = -1597$$

$$B = 2.3828$$

IF $P_{OO} \geq 1010$ Set $P_{OO} = 1010$

$$\ln R = A_3 + B_3 (\theta_{PUVO}) + C (\theta_{PUVO})^3 + D_3 (e)^{\frac{\theta_{PUVO}}{7}} + E_3 (\theta_{PUVO}) (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}}\right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

$$\theta_{PUVO} = 16.5239$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10} \; \Delta h_f \; W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF} \; H_f}{\eta_f}\right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

$$W_{TO} = W_T' - W_B$$

$$W_B = \left[\frac{2K_7 \quad H_2}{\gamma_{H2}-1} (P_{RNC})^{\frac{2}{\gamma_{H2}}}\right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2}-1}{\gamma_{H2}}}\right] \frac{A_{NB} \; P_{BNI}}{(R_{H2} T_{BIR})^{1/2}}$$

$$P_{RNC} = f(\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, R_G)$$

$$A_{NB} = K_{13} D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS} \left[1 + K_8 \left(\frac{W_T}{P_{TEFS}}\right)^2 \frac{T_{H2R}}{D^4{}_{TEF} \; M_{H2}} \left(\frac{\gamma_{H2}-1}{\gamma_{H2}}\right)\right]^{\frac{\gamma_{H2}}{\gamma_{H2}-1}}$$

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1\,(T_{H1})^3 + C_1\,(T_{H1})^2 + B_1\,(T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*_{TIF} = D_2\,(T_{H1})^3 + C_2\,(T_{H1})^2 + B_2\,(T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS} \cdot \left[1 + K_8\left(\frac{W_T}{P_{TIFS}}\right)^2 \frac{T_{H1R}}{D^4_{TIF}\,M_{H1}} \; \frac{\gamma_{H1} - 1}{\gamma_{H1}}\right]^{\frac{\gamma_{H1}}{\gamma_{H1}-1}}$$

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{HIR} = T_{TIF}$$

$$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\,(T_{HIR}, r_G)$$

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13. ABSTRACT

Six firings of the Rocketdyne J-2 rocket engine were conducted during test periods J4-1801-13, 14, and 15 on October 24, 31, and November 7, 1967, respectively, in Test Cell J-4 of the Large Rocket Facility. These firings were accomplished at pressure altitudes ranging from 98,000 to 107,000 ft to evaluate fuel pump start transient performance utilizing lower than minimum engine model specification fuel pump inlet pressure as required on AS-503 and subsequent flights. Engine components were thermally conditioned to temperatures observed in the S-II interstage/engine environment during the flight AS-501 countdown demonstration. The accumulated firing duration was 100.84 sec.

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inlet pressure						

1. Rocket motors -- J-2
2. " " -- Pump perfor—
3. Pumps — Perform—
4 Fuel pumps -

16-3